

# MANAGEMENT OF ACCUMULATORS



SIR. D. SALOMONS

# A LIST OF WORKS

PUBLISHED BY

## WHITTAKER & CO.

2 White Hart St., Paternoster Sq., London, E.C.

Accumulators, Salomons'.  
 Adams' Joints in Woodwork, 1s.  
 — Trigonometry, 2s. 6d. net.  
 Advice to Marine Engineers, Roberts,  
 2s. 6d.  
 Alexander's Model Engine Construc-

Bird's Geography, 2s. 6d.  
 Björling's Mechanical Engineer's  
 Pocket-Book, 3s. 6d. net.  
 — Pipes and Tubes, 3s. 6d. net.  
 Blakesley's Alternating Currents, 5s.  
 — Geometrical Optics, 2s. 6d. net.

WV 173.00

### Cornell University Library

THE GIFT OF

H. H. Norris

A 201282

15/III/06

4534

tricity, 2s. 6d.  
 Astronomy, Chambers, 1s. net.  
 Atlantic Ferry, Maginnis, 2s. 6d.  
 Auto Cars, Farman, 5s.  
 Ballooning, May, 2s. 6d.  
 Baret's Italian Dictionary, 2 vols.  
 21s.  
 Barter's Drawing, 3s. 6d.  
 — Woodwork, 6s.  
 Battery, Storage, Treadwell, 7s. 6d.  
 net.  
 — Galvanic, Bottone, 5s.  
 Beardmore's Drainage, 2s. 6d.  
 Beaumont's Colour in Woven Design,  
 21s.  
 Bicycle, Safety, Garratt, 3s.

— Petroleum, 2s.  
 British Locomotives, Cooke, 7s. 6d.  
 Brodie's Dissections, 42s.  
 Browne's (Jukes) Geology, 2s. 6d.  
 Builder's Quantities, Davis, 3s. 6d. net.  
 Building Specifications, Farrow,  
 3s. 6d. net.  
 Cabinet Making, Denning, 5s.  
 Cables, Electric Light, Russell, 10s. 6d.  
 Cakes, Marshall, 1s.  
 Calculus, Diff. and Integral, Wyatt,  
 3s. 6d.  
 Carpentry and Joinery, Fletcher, 5s.  
 net.  
 Cellar Book, Dodsley, 1s. 6d.  
 — — Farley, 1s. 6d.

Centr  
Ga  
Cham  
Chem

Chem  
2s.  
Chem

Chip  
7s.

Coal  
Coils  
Cold  
Colo  
21.  
Conc  
Cook

Cook  
Coop  
Copp  
Crap  
2s.

Crell  
1s.

Cutly  
Davi  
Denn

Desi  
Desi  
Dicti  
Dicti  
1c

Diss

Pa

Pa

In

Dod

27 JUN 1914  
1 APR 1915  
6 APR 1925

# HOME USE RULES.

Books not needed for instruction or research are returnable within 4 weeks.

Volumes of periodicals and of pamphlets are held in the library as much as possible. For special purposes they are given out for a limited time.

Borrowers should not use their library privileges for the benefit of other persons.

Books not needed during recess periods should be returned to the library, or arrangements made for their return during borrower's absence, if wanted.

Books needed by more than one person are held on the reserve list.

Books of special value and gift books, when the giver wishes it, are not allowed to circulate.

ngineer's

6s.

5s.

7s. 5s.

os. 6d.

5s.

omons':

5s. 6d.

tone, 1s.

Distribu-

vol. ii.

ngineers,

7s. net.

4s. net.

7s. net.

, Kapp,

lligence,

hes, and

6d. net.

3s. 6d.

6d.

k, Edg-

2s. 6d.

Bottone,

Hobart,

r, 2s. 6d.

1s. net.

4s. 6d.

net.

Electricity, 100 years ago, 4s. 6d. net.  
— in its application to Telegraphy, Herbert.

— in our Homes, Walker, 6s.

— Supply, Gay and Yeaman.

— Gibbings, 6s.

— and Magnetism, Ashworth, 2s. 6d.

— Bottone, 2s. 6d. net.

— Houston, 2s. 6d. net.

— Maycock, 2s. 6d. net.

Electro-motors, Bottone, 3s.

Electro-platers' Handbook, Bonney, 3s.

Electrolytic Analysis, Neumann, 6s.

— Peerage, 10s. 6d.  
Dodsley's Cellar Book, 1s. 6d.  
Drainage, Beardmore, 2s. 6d.  
— Nadiéine, 1s.  
Draughtsmen's Work, 1s. 6d.  
Drawing and Designing, Leland, 2s.  
— for Marine Engineers, Roberts, 6s.  
— Cards for Marine Engineers, Sothern, 3s. 6d. net.  
— Woodwork, Barter, 3s. 6d.  
Dynamo, Bottone, 2s. 6d.  
— Hawkins and Wallis, 15s.  
— How to Manage, Bottone, 1s.

- Elliott's Gas and Petroleum Engines, 2s. 6d.  
 — Industrial Electricity, 2s. 6d.  
 Engineer Draughtsmen's Work, 1s. 6d.  
 — Fitting, Horner, 5s.  
 — Locomotive, McDonnell, 1s.  
 Engines, Model, Alexander, 6s. net.  
 English and American Lathes, Horner, 6s.  
 Experiments with Vacuum Tubes, Salomons, 2s.  
 — Electrical, Bonney, 2s. 6d.  
 Explosives, Manufacture of, Guttman, 2 vols. 2l. 2s.  
 Farley's Cellar Book, 1s. 6d.  
 Farman's Auto Cars, 5s.  
 Farrow's Specifications for Building Works, 3s. 6d. net.  
 — Stresses and Strains, 5s. net.  
 Field Work and Instruments, Walmisley, 6s. net.  
 Findlay's Railway Working, 7s. 6d.  
 Fitting, Engineer, Horner, 5s.  
 — Electric, Maycock, 6s.  
 — Electric Light, Allsop, 5s.  
 Fletcher's Architectural Hygiene, 5s. net.  
 — Carpentry and Joinery, 5s. net.  
 — Steam-Jacket, 1s. 6d.  
 Foden's Mechanical Tables, 1s. 6d.  
 French Technical Dictionary, Webber, 4s. net.  
 Friction and its Reduction, Wheeler, 3s. net.  
 Galvanic Batteries, Bottone, 5s.  
 Garratt's Modern Safety Bicycle, 3s.  
 Gas and Gas Fittings, Hills, 5s. net.  
 Gas and Petroleum Engines, 2s. 6d.  
 Gaseous Fuel, Thwaite, 1s. 6d.  
 Gay and Yeaman's C. S. Electricity Supply.  
 Gearing, Helical, Horner, 5s.  
 Geography, Bird, 2s. 6d.  
 Geology, Jukes-Browne, 2s. 6d.  
 Geometrical Optics, Blakesley, 2s. 6d. net.  
 Gibbings' Electricity Supply, 6s.  
 Gray's Electrical Influence Machines, 5s.  
 Greene's Saints and their Symbols, 3s. 6d.  
 Greenwell and Elsdon, Road Construction, 5s. net.  
 Griffiths' Manures, 7s. 6d.  
 Guttman's Manufacture of Explosives, 2 vols., 2l. 2s.  
 Guttman's Percentage Tables for Analysis, 3s. net.  
 Harris' Practical Chemistry, 3 vols. 4s.  
 Hatch's Mineralogy, 2s. 6d.  
 Hatton's Mathematics, 2s. 6d. and 3s.  
 Hawkins' and Wallis's Dynamo, 15s.  
 Heat Engines, Anderson, 6s.  
 Helical Gears, Horner, 5s.  
 Herbert's Telegraphy.  
 — Telephone System of the Post Office, 3s. 6d.  
 Hering, Electric Railways, 4s. 6d. net.  
 Hertzian Waves and Wireless Telegraphy, Bottone, 3s.  
 Hewitt's Organic Chemical Manipulation, 4s. 6d.  
 Hills' Gas and Gas Fittings, 5s. net.  
 Hobart's Electric Motors, 12s. 6d. net.  
 Hobart and Turner's Insulation of Electric Machines, 10s. 6d. net.  
 Hobbs' Electrical Arithmetic, 1s. net.  
 Hoblyn's Medical Dictionary, 10s. 6d.  
 Horner's Helical Gears, 5s.  
 — Iron-founding, 3s. 6d.  
 — Lathes, 6s.  
 — Metal Turning, 3s. 6d.  
 — Pattern Making, 3s. 6d.  
 — Principles of Fitting, 5s.  
 Houston's Electrical Measurements, 4s. 6d. net.  
 — Electricity and Magnetism, 2s. 6d.  
 — Transmission of Intelligence, 4s. 6d. net.  
 Hurter's Alkali Makers' Handbook, 10s. 6d.  
 Hutton's Mathematical Tables, 12s.  
 Hydraulic Motors and Turbines, Bodmer, 15s.  
 Hygiene, Architectural, Fletcher, 5s. net.  
 Incandescent Lighting, Houston, 5s.  
 Indicator Handbook, Pickworth, 2 vols. 3s. each, net.  
 Induction Coils, Bonney, 3s.  
 — Motors, Hobart, 12s. 6d. net.  
 Industrial Electricity, 2s. 6d.  
 Insulation of Electric Machines, Turner and Hobart, 10s. 6d. net.  
 Iron and Steel Structures, Twelve-trees, 6s. net.  
 Ironfounding, Horner, 4s.  
 Italian Dictionary, Baretti, 21s.  
 — Technical Dictionary, Webber, 4s. net.  
 Jukes-Browne's Geology, 2s. 6d.

Cornell University Library

arV17300

The management of accumulators;



3 1924 031 241 239

olin,anx

## WHITTAKER'S

### PRACTICAL HANDBOOKS FOR ENGINEERS.

---

- ALLSOP, F. C. Practical Electric Light Fitting. 5s.
- BLAKESLEY, T. H. Alternating Currents of Electricity. 5s.
- BODMER, G. R. Hydraulic Motors and Turbines. 15s.
- BOTTONE, S. R. Galvanic Batteries. 5s.
- CRAPPER, E. H. Electrical Measurements. 2s. 6d.
- EDGUMBE, K. Electrical Engineers' Pocket Book. 3s. 6d. net.
- ELLIOTT, A. G. Gas and Petroleum Engines. 2s. 6d.
- ,, Industrial Electricity. 2s. 6d.
- GAY, A., and YEAMAN, C. H. Central Station Electricity Supply. 10s. 6d. net.
- GIBBING, A. H. Municipal Electricity Supply. 6s.
- GRAY, J. Electrical Influence Machines. 5s.
- HAWKINS, C. C., and WALLIS, F. The Dynamo: its Theory, Design and Manufacture. 15s.
- HOBART, H. M. Electric Motors.—Continuous Current Motors and Induction Motors. 12s. 6d. net.
- KAPP, G. Transformers for Single and Multiphase Currents. 6s.
- ,, Electric Transmission of Energy. 10s. 6d.
- LODGE O. Lightning Conductors and Lightning Guards. 15s.
- LOPPE and BOUQUET. Alternate Currents in Practice. 6s.
- MAYCOCK, W. P. Alternating-current Circuit and Motor. 4s. 6d. net.
- ,, Electric Lighting and Power Distribution. Vol. I. 6s.; Vol. II. 7s. 6d.
- ,, Electric Wiring, Fittings, Switches and Lamps. 6s.
- ,, Electric Wiring Tables. 3s. 6d.
- RIDER, J. H. Electric Traction. 10s. 6d. net.
- RUSSELL, S. A. Electric Light Cables and Distribution of Electricity. 10s. 6d.
- SALOMONS, Sir D. Electric Light Installations. Vol. II. Apparatus. 7s. 6d.
- STILL, A. Alternating Currents and the Theory of Transformers. 5s.
- TURNER, H. W., and HOBART, H. M. Insulation of Electric Machines. 10s. 6d. net.
- WALKER, S. F. Electric Lighting for Marine Engineers. 5s.
- ,, ,, Electricity in our Homes and Workshops. 6s.
- WHITTAKER'S. Electrical Engineers' Pocket Book. 3s. 6d. net.
- ,, Mechanical Engineers' Pocket Book. 3s. 6d. net.

WHITTAKER & CO., 2 White Hart Street, LONDON, E.C.

THE  
MANAGEMENT OF ACCUMULATORS



Cornell University  
Library

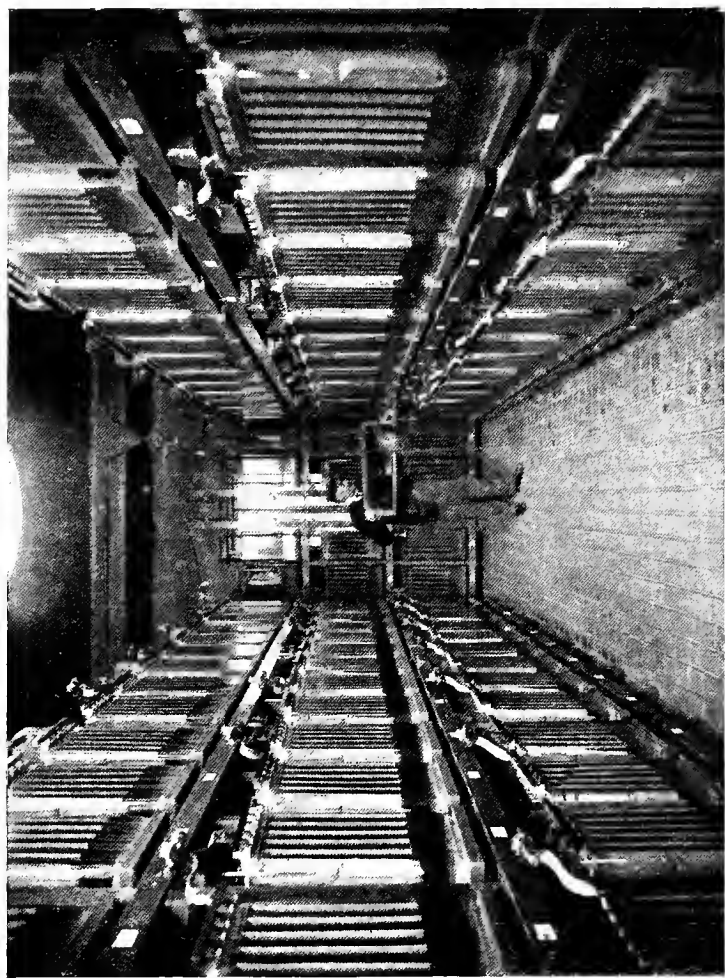
The original of this book is in  
the Cornell University Library.

There are no known copyright restrictions in  
the United States on the use of the text.

<http://www.archive.org/details/cu31924031241239>







BROOMHILL ACCUMULATOR HOUSE.

Showing Attendant using the Cradle to move a Cell.

# THE MANAGEMENT OF ACCUMULATORS

## *A PRACTICAL HANDBOOK*

BY

SIR DAVID SALOMONS, BART., M.A.

LATE VICE-PRESIDENT OF THE INSTITUTION OF ELECTRICAL ENGINEERS

ASSOCIATE OF THE INSTITUTION OF CIVIL ENGINEERS

MEMBER OF THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

MEMBRE DE LA SOCIÉTÉ INTERNATIONALE DES ÉLECTRICIENS

MEMBER OF THE PHYSICAL SOCIETY OF LONDON

FELLOW OF THE ROYAL ASTRONOMICAL SOCIETY

FELLOW OF THE CHEMICAL SOCIETY

ETC., ETC., ETC.

*NINTH EDITION, REVISED*

WITH ILLUSTRATIONS

*An Edition, mostly re-written, of Volume I. of  
'Electric Light Installations and the Management of Accumulators'*

D. VAN NOSTRAND & COMPANY

23 MURRAY AND 27 WARREN STREETS, NEW YORK, AND  
WHITTAKER & CO., LONDON

1906

GLASGOW : PRINTED AT THE UNIVERSITY PRESS  
BY ROBERT MACLEHOSE AND CO. LTD.

## PREFACE TO THE NINTH EDITION.

THIS little book aims at filling a gap which, in practical scientific literature, is very noticeable. It presents to the reader a general survey of the practice of Electric Lighting and Management of Accumulators, with such recommendations as are likely to assist him in obtaining successful results. The former editions were so rapidly disposed of that it was evident a demand for such a work existed in this country, as well as abroad, since it has been translated into the French, German, Spanish and other languages.

A ninth edition having been called for, the opportunity has been taken to thoroughly revise the work, a very considerable portion having been rewritten. On account of the increasing size of the book, the last edition was issued in three volumes—Vol. I., Accumulators; Vol. II., Apparatus; Vol. III., Application. It has been decided to issue the ninth edition of Vol. I.—Accumulators—as an independent book, in consequence of a demand for this volume existing among many classes who are not specially interested in electric light installation, and would

therefore prefer the volume on the special subject dealt with, to be complete in itself. With the advance of Science and the Arts, the Accumulator has stepped in for road propulsion, X Ray work, and a vast number of small domestic uses. This edition, therefore, has a special chapter devoted to the treatment and application of small Secondary Cells, and the author trusts that this method of procedure will meet with favour. Many of the types described in the last edition have become obsolete, and their description would belong to a book dealing with the history of the Accumulator rather than to one intended for practical purposes. As a natural consequence, references to extinct types have been omitted in this edition, except where it becomes necessary in order to make clear the description of existing cells.

No other book has yet been written on the special subject of the practical management of an accumulator—a circumstance which has created some surprise, although, on examination, the reasons become clear enough. Two classes of persons are interested in batteries—namely, the manufacturer and the purchaser. The former, as a rule, knows comparatively little of the properties of batteries, for his knowledge is confined to laboratory tests, and it is not to his interest to publish all the shortcomings of his wares. On the other hand, the true knowledge of how a battery will act is gained only by experience extending

over a long period, during which the accumulator is almost invariably in the hands of an unprofessional user, who seldom knows sufficient to enable him to examine the question for himself. Therefore, the privilege remains with a very few to observe, scientifically as well as practically, the working of batteries; and out of this limited class not many have the time or opportunity to write on the subject. The author has attempted to fill this blank which lies between the manufacturer of cells and the general user, and he trusts that benefits will accrue to both from the perusal of these pages.

The writer feels confident that the directions here laid down, if carefully followed, will prove of great service, so that professional advice will very rarely be required. In fact, this little book is the outcome of years of labour and of an almost countless number of experiments, undertaken without considering trouble or cost; for solely in this manner can reliable results be obtained. Only those types of cells largely in practical use are dealt with. The many other types that exist would be more properly described in a history on the subject which this little treatise is not intended to be.

It is possible that some of the types, existing at this moment more or less in an experimental form, may prove to be superior to those now in general use; but experience is as yet insufficient to show which these are.

The Introductory Chapter is practically a reproduction of an article contributed by the author of this work to "Lippincott's Magazine," and which, by the kind permission of the editor, he is now able to submit to his readers. The object of its insertion here is to afford an opportunity of presenting an elementary view of an electric installation to those who may seek it.

To friends and correspondents, as well as to his former tutor Mr. B. Loewe, F.R.A.S. (who died in the year 1892 regretted by all who knew him), the author is much indebted for so many valuable suggestions that have materially assisted him in his difficult task.

His thanks are also due to the numerous firms who have kindly lent the blocks from which most of the plates in this book were printed. The presence of these illustrations will prove of great advantage to readers, so that their gratitude must be added to that of the author.



# CONTENTS.

CHAP.	PAGE
PREFACE,	vii
LIST OF ILLUSTRATIONS,	xiii
INDEX OF TERMS, -	xv
INTRODUCTION,	I
I. DESCRIPTION OF CELLS AND THEIR MODE OF EMPLOYMENT,	23
II. SETTING UP THE CELLS AND THE ACCUMULATOR HOUSE,	60
III. CHARGING,	91
IV. DISCHARGING,	133
V. FAILURES, THEIR CAUSES AND REMEDIES,	140
VI. TESTING A SECTION,	162
SUMMARY,	170
INDEX,	175



## LIST OF ILLUSTRATIONS.

FRONTISPIECE : (I.) BROOMHILL ACCUMULATOR HOUSE  
(Showing Attendant using cradle to move a cell).

FRONTISPIECE : (II.) BROOMHILL ACCUMULATOR HOUSE  
(Showing Counter E.M.F. Cells at end of room).

FIG.		PAGE
1	23-PLATE E.P.S. CELL IN GLASS BOX,	50
2	17-PLATE E.P.S. WT TYPE CELL IN WOOD LEAD- LINED BOX,	50
3	TUDOR POSITIVE PLATE,	50
4	THREE TUDOR CELLS,	50
5	TUDOR CELLS IN LEAD-LINED WOOD BOXES,	52
6	CHLORIDE PLATES. POSITIVE GROUP AND NEGATIVE GROUP,	52
7	CHLORIDE COMPLETE CELL,	52
8	TEN EXIDE CELLS IN CRATE, -	54
9	SMALL EXIDE CELLS,	54
10	D.P. PORTABLE CELLS,	54
11	D.P. LEAD STRIP POSITIVE,	54
12	D.P. NEGATIVE PLATE,	54

FIG.		PAGE
13	D.P. CELLS,	56
14	LUMFORD POSITIVE PLATE AND SECTION,	56
15	D.P. LUMFORD NEGATIVE PLATE AND SECTION,	56
16	D.P. LUMFORD HEAVY TYPE CELLS,	56
17	N.S. CELL. HORIZONTAL SECTION, -	56
18	N.S. CELL. SECTION,	56
19	N.S. CELL. COMPLETE,	58
20	N.S. CELL. THE PELLETS BEFORE BEING PLACED IN POROUS JAR,	56
21	PETO AND RADFORD CELLS,	58
22	PETO-RADFORD ARMoured ACCUMULATOR,	58
23	PETO-RADFORD ARMoured PLATE,	58
24	INSULATING NUT,	58
25	OIL INSULATOR. GENERAL VIEW,	61
26	OIL INSULATOR. SECTION,	61
27	POCKET POLE TESTER,	74
28	POCKET POLE TESTER, WITH SPIRIT-LEVEL COMBINED,	75
29	ACIDOMETER (ORDINARY TYPE),	80
30	ACIDOMETER (HICKS'), -	81
31	PIPETTE,	82
32	HOLDEN TYPE OF ACIDOMETER,	83
33	CELL-TESTING VOLTMETER,	94
34	LOWER END OF PLATES (BUCKLED),	98
35	CELL-INSPECTION LAMP, -	100
36	RESISTANCE FRAME AND SWITCH,	152

## INDEX OF TERMS.

$\text{H}_2\text{O}$  = Water.

$\text{H}_2\text{SO}_4$  = Sulphuric acid.

$\text{PbO}_2$  = Lead peroxide.

$\text{PbO}$  = Lead oxide.

H = Hydrogen.

O = Oxygen.

Pb = Lead.

E.M.F. = Electric motive force, or pressure of current.

Ampère = Unit of measure for quantity of current.

Volt = Unit of measure for pressure of current.

Watt = Volt  $\times$  Ampère = Unit of force.

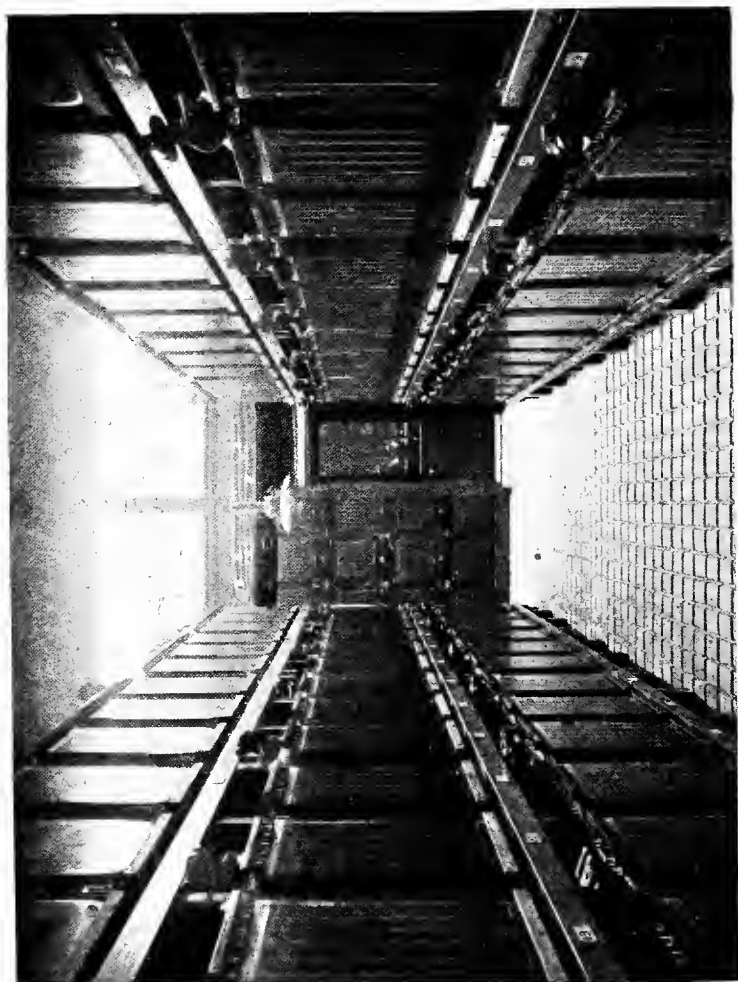
Electrolyte = The liquid put in a cell.

s.g. = Specific gravity.

c.p. = Candle-power.







BROOMHILL ACCUMULATOR HOUSE.  
The Counter E.M.F. Cells are seen at end of the room.



# THE MANAGEMENT OF ACCUMULATORS

## INTRODUCTION.

THE object of this chapter is to place before the reader a general view, expressed in a simple way, of electric lighting. This may prove convenient to many persons who may not feel disposed to peruse the whole book, but may have obtained it for purposes of reference. Most of the points mentioned in this introduction will, therefore, be found treated in a more complete manner in succeeding chapters.

To bring to the understanding of the general reader how the electric light is produced is no easy matter. (By "general reader" is meant a person whose scientific knowledge is of the most elementary character.) The following description is an attempt in this direction. In order that the untrained mind may realise natural laws and phenomena which are either unknown or unfamiliar to it, comparisons have to be made between them and the phenomena which

are within its knowledge. This is not a strictly scientific method of proceeding, and, when employed in the present chapter, any comparisons given must be restricted merely to the statement made; there must be no further deductions, whether such deductions are right or wrong.

Practical electricity is the application of a certain known form of energy to practical ends, such as telegraphy, telephony, lighting, motive power, welding, chemical operations, medicine, and an infinite number of other purposes. The subject to be treated here will be that of lighting and motive power only. This divides itself into three parts: (1) The production of the energy, *i.e.*, electric energy; (2) the means of conveying that energy to the point or points where it is to be used; and (3) the apparatus for giving the desired results.

Although there are various ways of producing electricity, from the rubbing of a piece of sealing-wax on the coat sleeve to the vast engines employed at large central lighting stations, yet here will be considered only such methods of obtaining the force as are in practical use on a moderate scale.

The current for electric lighting may be produced either from chemical batteries or from machines termed dynamos. Thermo-electric machines also exist, but so far, they have taken no place of practical importance. The dynamo is an apparatus, a portion of which has to be revolved in order to produce a

current, and consequently requires some motive power, which is obtained from a steam-engine or some other source. The fact must be remembered that a steam-engine derives its power from the fuel in the boiler furnace, or from gas, petroleum, or some other material, being consumed—to use a common phrase—for in reality it is simply the material passing from one chemical state to another, no actual consumption taking place at all. It will thus be observed that the power obtained from all engines is derived, in the first instance, by a chemical process, and is, therefore, comparable with a complex chemical battery. It might be thought that, when the current is produced by water-power, chemical action is no longer the source of current-production; but this is not necessarily so, for the water, whence the power is derived, has been raised from low levels to high levels; this raising having been accomplished by the sun's heat, which may be due to chemical action. The water was raised from low levels in the form of vapour, and deposited at higher ones in the form of rain. Therefore, it might be assumed that, electricity can probably be produced only by chemical action, and that, whenever any chemical action takes place, electricity is produced; and in our world the chemical hypothesis is probably true. Even the electricity obtained by rubbing sealing-wax is derived from chemical action in the human body. As to whether the sun's heat is due to chemical action taking place

at its surface or not, that is a question still occupying the attention of scientific men; because it is doubtful whether, at the high temperatures known to exist there, chemical action is possible at the present time. Should this prove to be the case, then the sun's heat may result from some antecedent atomic or molecular motion of matter produced by the action of chemical affinity, or by mechanical motion of some kind, which may, in its turn, have been originated by heat, gravity, or other undiscovered cause.

However, it is usual—without entering into further refinements—to speak of the electric current as being produced either by means of an engine of some kind, water-power, or from batteries. The engines employed are usually steam or gas, and both are so familiar to everyone that to describe them is unnecessary. The apparatus revolved by the engine, and termed the dynamo, wherein the current is actually produced (or, more strictly speaking, the apparatus in which the power derived from the engine is converted into electric energy) will claim our attention after a brief reference to batteries.

Batteries are divided into primary and secondary. The former are those wherein the materials, part or all of them, become exhausted, and at this stage fail to supply electricity, unless a portion or the whole of the materials is renewed. The secondary battery is one which becomes exhausted exactly in the same

way as the primary, but the chemical contents are of such a nature that it is merely necessary to pass a current of electricity through the battery in order to restore them to their original condition. To give a practical instance: everybody is familiar with the primary cell, consisting of a pot of weak sulphuric acid, in which are immersed two plates—one of copper, one of zinc—which are not permitted to touch in the liquid, but are connected with one another outside the liquid by means of a wire of any length, the ends being joined to the plates respectively. Under these conditions the fluid bubbles like soda-water (which indicates that some of it is being converted into gas), and a current flows through the wire. This is a simple illustration of chemical and electrical action proceeding at the same time, and which, as already stated, must necessarily take place although not always self-evident.

On disconnecting one end of the wire from one of the plates the bubbling ceases, which shows that the action has been arrested. In the course of the wire an electric lamp, a motor, or an instrument for indicating the presence of a current, or any other apparatus, may have been inserted; and all the results so well known, which can be produced by means of an electric current, would have made themselves manifest. But, of course, no appreciable quantity of light or power will be produced from such an experimental cell; many such cells coupled

together would, to be of practical service, be needed, and the combination is termed a battery. In a short time the zinc plate in the cell is dissolved, the power of the liquid also becomes exhausted, and the production of the electric current thereupon ceases. But supposing these two plates, instead of being copper and zinc, had been one lead and the other double oxide of lead, then, although the current produced would cease to flow after a time, instead of requiring a portion of the contents of the cell to be renewed, it would only be necessary to pass through the cell a current produced from other source in order to restore its vitality. Such a combination is termed a secondary cell; and a number of these, suitably connected together, form a secondary battery, very commonly known under the name of an accumulator. An accumulator, therefore, is nothing more than a primary battery in which the chemicals can be renewed as often as required by merely passing a current of electricity through it, such current in practice being produced by means of an engine and a dynamo. It may also be observed that the primary battery at the present moment is not a suitable means for producing electricity on a large scale, for, apart from expense, the necessity to replace new chemicals in the cells from time to time involves considerable trouble and inconvenience, whereas to replenish an accumulator by running an engine is a very simple matter.

Turning to the dynamo, no attempt can be made

here to enter into a full description of the apparatus, which is made in an almost unlimited number of ways; but sufficient explanation may be given of its general principle in order to show how a current is produced from it, the principle being the same in all types, no matter how the machine may be constructed.

Dynamos are of two kinds: one made to produce a continuous current, and the other an alternating current. Although these currents are very dissimilar in character, no difference is to be observed when they are employed to give light. A continuous current may be compared to a liquid wherein waves are continually progressing in one direction. The direction towards which the waves are moving is termed the positive direction, and that from which they come, the negative. Hence, if a wire with a current flowing in it be attached to a lamp in such a manner that the waves move towards the point where the wire is attached to the lamp, it would be said that this part of the lamp is attached in such a way as to receive a positive current; and the other part where the current leaves it (since the waves will evidently move away from this part) is termed the negative. In this explanation the lamp must be regarded as a portion of the circuit, modified in such a fashion as to be capable of converting the electric energy into light. The reader will, therefore, observe that, when a positive or negative current is spoken of, it simply indicates direction. Notwithstanding this, positive

## 8 MANAGEMENT OF ACCUMULATORS

electricity and negative electricity have a variety of phenomena peculiar to each.

The alternating current may be regarded as a fluid in which a wave proceeds first in one direction and then in the other, see-saw fashion; and in practice these changes of direction take place as frequently as from fifty to two hundred times per second.

Instruments employed for continuous currents may contain iron and permanent magnets, but for the alternating the latter must be completely absent, and any iron employed in their construction must be very soft and much subdivided, or it will become extremely hot.

The dynamo that is to produce the continuous currents consists of two parts—one stationary, and one to be revolved. In the most usual type the stationary portion consists of a powerful electro-magnet, horseshoe in shape, the free ends of the horseshoe being termed poles. These poles are so arranged as to permit the moving part, called the armature, to revolve between them. The armature consists of a spindle running in bearings, and is revolved by motive power, either by being connected directly with the engine or indirectly by means of a belt, in which latter case the spindle carries a pulley. Upon the spindle is placed a suitable framework, and wire is wound upon this in a special manner so as to form a continuous coil, which may contain (as it generally does,) or may not contain, some soft iron.



When the armature is removed from a machine it has somewhat the appearance of a short bolster with a spindle pushed through. The bolster part, on close examination, will be found to consist of the coil of wire already mentioned. This wire coil portion revolves between the magnet poles. The spindle at one end carries a number of copper plates, placed radially and close together, so as to form in appearance a solid cylinder, termed the commutator. Each plate is insulated from the next and from the spindle. By insulation is meant that some substance is placed between plate and plate, and between plates and spindle, through which electricity will not pass. Upon this commutator rest two copper brushes, to which are attached the wires (in a shunt machine) which lead to any point where electric energy is required. Every plate in the commutator has a wire attached to it, the other end of the wire being in connection with some point of the armature coil. It will thus be seen that any current produced in the armature will travel to the copper plates, and enter the brushes which press upon them, and so pass on into the wires (generally termed cables, mains, or lines) and travel to the point required. When the armature is revolved, the plates of the commutator successively pass under the brushes, which usually consist of a group of fine copper wires, or thin plates, of considerable length to give them elasticity and to allow of their being moved forward to make up for wear

and tear. In all cases the current produced by means of dynamos is alternating. Consequently, when a continuous current is wanted it must be changed from one form of current into the other. This is effected by means of the commutator, just described, as the name would appear to imply.

A portion of the current produced is employed to excite the electro-magnets. Permanent magnets may be used—in fact, they are still used in France for dynamos placed in lighthouses—but for general purposes the electro-magnets are cheaper, and have many other advantages. A piece of soft iron, wound round and round with wire, which has a current passing through it, becomes a powerful magnet; such a combination being termed an electro-magnet. Iron, under these conditions, is said to be “excited.” When the electro-magnet of the dynamo is excited, the armature is in an extremely powerful magnetic field; which means that it is strongly under magnetic influence. If the spindle is revolved subject to these conditions, and the wires leading from the brushes are connected so as to form a closed circuit with appreciable resistance, it will be found that the power required to turn the spindle with the armature increases as the speed is raised. The best comparison to make is that of turning a fan in a barrel of treacle: the quicker the fan is turned, the greater will be the resistance to its motion. The very revolving of the armature before the poles of a magnet, which, as

explained, is nothing more than a specially-wound coil of wire, produces in it a current of electricity; and the faster the coil is turned, the greater the pressure of the current. The quantity of electricity produced is dependent upon the resistance of the circuit.

The resistance is made up, in the simple case imagined, of the wire in the armature, the length of which is invariable, and of the variable length of wire of the outside circuit, the ends of which are joined to the brushes. Evidently, the longer this wire is, the greater will be the resistance offered to the passage of the current; and, if the pressure were to remain unaltered for two different lengths of this wire, the quantities of current which would flow through it must necessarily vary with its length (*i.e.*, if the armature-coil resistance is not considered). The resistance of the armature coil is always very small and may practically be neglected, so that the current flowing in the system may be considered proportional to the resistance of the circuit outside the machine. In an electric-light installation the resistance of the outside circuit would be virtually proportional to the number of lamps in use at any time, since adding or subtracting lamps increases or diminishes the resistance of this circuit.

In a well-constructed dynamo, running at a given speed and intended to produce current for a certain number of lamps, the pressure should remain

constant, whether one lamp, or more, be in use upon the circuit ; and this is of great importance, for otherwise the light from the lamps would vary according to the number employed. When such self-regulation cannot be obtained, electric governors secure constant pressure.

In other classes of installations the various apparatus placed in the circuit take the place of lamps.

One form of alternating-current dynamo consists of a number of coils placed upon the periphery of a wheel, and which are revolved before electro-magnets excited from a small continuous-current machine such as that just described. The arrangement of the various parts permits an alternating current to be produced in the moving coils. This current is collected by means of brushes, as in the last case ; but the commutator is replaced by two collecting rings of metal connected with the wire upon the moving coils, but otherwise insulated. The conditions for regular pressure and quantity of current, in the case of alternating currents, being very complex, they cannot be considered in an elementary discussion of the subject. These descriptions of the two usual types of dynamo are only of the most superficial kind, the aim being to give merely a general idea of the machines.

Having dealt with the production of the electric current, it becomes necessary to consider how it is

conveyed to those points where it is required, and then to examine the apparatus used for obtaining practical results.

In order that the current may travel, the circuit must be complete. The circuit may be compared to a system of hot-water pipes, such as are used for warming hot-houses. In a hot-water system there is a boiler : a flow and a return circulating-pipe, with pipe-coils at various points for giving off heat at places where warmth is required. In an electric installation the dynamo replaces the boiler : flow and return pipes are represented by the two conducting mains, and the pipe-coils by lamps, motors, and other apparatus. In a hot-water system it is perfectly evident that whatever be the quantity of water leaving the boiler, the same must return to it, and the quantity of water passing through every part of the flow and the return pipes in a given time must be alike. It is so with the electric current : whatever may be the quantity of the current starting from the dynamo, the same quantity comes back to it. Also the whole of this quantity must pass through the mains. But it is different with the pressure : this diminishes in proportion to the work done by the current. Consequently, the pressure diminishes as the current advances on its path. Comparing this again with the hot-water system, the analogy is fairly complete ; for the current may be regarded as losing heat (this is often disguised) as it advances, since in

losing its pressure it produces heat, and the hot water does the same.

The passage of a current through a conductor cannot be effected without loss of power, *i.e.*, diminished pressure. Loss of power means work done. If this work has a useful purpose, it is not a loss in the common sense of the word; but in all other cases it is waste. Any pressure of the current lost in a lamp produces a desired result. Since this is not so for the mains, the system must be constructed in such a manner that as little loss as possible shall occur in conducting the current from point to point, where practical results are needed; and that is effected by making the mains as large as possible. The size of the mains is limited only by the consideration of their cost. To sum this up, nearly the whole pressure of the current, in a well-designed installation, may be regarded as being lost in passing through the lamps, motors, and other apparatus.

It would thus seem that the larger the section of a wire the less resistance does it offer to the passage of a given current. One wire double the diameter of another will offer four times less resistance. If the current passing through any wire is doubled, the loss of pressure in travelling a given distance will be four times greater, three times the current, nine times: *i.e.*, the waste increases as the square of the current. In electric lighting, the waste invariably consists in producing heat at places in the circuit

where it is not required ; and if this is generated in too great a degree by reason of the mains offering too much resistance—that is, being too small in section—a fire may result. There is waste also by leakage, but this exists only to an inappreciable extent in a well-designed installation. To avoid the possibility of a fire, through overheating, the current is made to pass in its course, at suitable points, through short pieces of metal far more fusible in nature than the material of which the conductors are made. The conductors are usually of copper. The fuses, as a rule, consist of tin wire, and are generally called “safety junctions.” Then, if the current rises, from any cause, beyond a certain limit, the safety junctions melt and cut the circuit before any damage is done. There are other devices also for cutting off the current in case of need, and they are described in a sister volume.

The only apparatus in connection with an electric-light installation that require to be considered here are the arc lamp, the incandescent lamp, the motor, the switches, the instruments for indicating the quantity and pressure of the current, and the meter.

In the arc lamp the current passes through two carbon rods, which are separated from one another by a very short distance. In order that the current shall leap this interval, the rods are made to touch one another for a moment, and then to separate. A

flame, consisting of heated gases, is to be observed between these carbon rods, which must not be mistaken for visible electricity. The powerful light is produced by the intense heat to which the ends of these rods are raised. Suitable apparatus is connected with these rods in order that they may be fed as they burn away: otherwise, the distance between them will increase, and eventually the current will cease to flow.

The incandescent, or glow, lamp consists of a very fine filament of carbon, hermetically sealed in a glass globe from which the air has been exhausted. The ends of the filament reach the outside of this globe by being attached within it to two platinum wires, which pass through the glass to the outside, and there they are dealt with in some convenient way whereby they may be joined to the circuit. When so joined, the current enters the filament at one end and leaves it by the other, the filament becoming white-hot during the time that the current passes through it, but is not consumed, since there is no air present. The high resistance of the carbon filament necessitates a great loss of pressure in the current during its passage through it, and is converted into light-giving heat. If the pressure of the current is greater than that for which the lamp was constructed, too much current will pass through the filament and it will be destroyed. On the other hand, if the pressure is insufficient, the temperature



to which the filament ought to be raised will not be reached, and the light will be far less than it should be under normal conditions. The light given by any lamp diminishes in far greater proportion than the equivalent fall in the pressure of the current; and the inverse is true. For instance, a lamp intended to give a certain light with a given pressure of current would yield less than half its light with a fall of 10 per cent. in pressure. On the other hand, a 5 per cent. increase of pressure above the normal would produce at least double the light for which the lamp was made. Other forms of lamps exist.

A motor is identical with the dynamo. In the latter case the armature is revolved and a current produced, but when a current is sent into a dynamo, the armature revolves—in other words, it becomes a motor. Here is presented, perhaps, the simplest way of conveying power that has ever been discovered. If a lathe or other machine has to be turned by power at any given place, it will be necessary merely to convey to that place two wires for conducting the current and a motor to be attached to them. Though heavy, a motor is compact; and a man can, on a properly-designed truck, move about without difficulty from place to place such a machine up to the size, say, of a 10-horsepower motor. Apart from the rapidity and ease with which motive power may be installed, wherever it is desired, there are eliminated the dangers and complications which exist

more or less in connection with the forms of motive power hitherto employed.

In order to light and put out a lamp, or start and stop a motor, the current must be cut. Simple apparatus are employed which break the metallic continuity of the circuit, this being all that is necessary. Such devices are termed switches.

Two instruments are used in order to observe what is taking place upon the circuit. The one is termed an ammeter, and indicates the quantity of current, the unit being termed an ampère. The other instrument is called a voltmeter, and registers pressure, the unit being termed a volt. There are also meters, equivalent to a gas-meter, whereby the electrical energy used over any given time is recorded.

There are two systems of distribution—one termed the series and the other the parallel. Each of these systems has many sub-divisions, also combinations; but only the simple methods need be referred to.

In the series system the conductor consists of one continuous circle. The lamps and other apparatus which are inserted form a part of such conducting ring. In this method high pressure currents have to be used, because there is a fall of pressure as the current passes through each succeeding lamp or other piece of apparatus.

The glow-lamps mostly in use require a pressure of 100 volts. As just pointed out, volt is the unit measure of pressure. Suppose, therefore, a circuit

to contain 50 such lamps, 5,000 volts would be required in order that they might give their normal light. Arc lamps, whether made to give a large or a small light, need a pressure of 50 volts to work them. Occasionally it may be a little more or a little less, according to the make of the lamp. Therefore, 50 such lamps upon a series circuit would require a current having a pressure of 2,500 volts. A pressure exceeding 500 volts with a continuous current, and 200 volts with an alternating current, may prove fatal to human life under certain conditions.

In the parallel system, which is free from danger, since high pressure is rarely employed in connection with it, the flow and the return mains may be supposed to be of equal length and laid parallel with one another. At various points along these mains branch wires start, a lamp or motor being placed in the course of each branch, so that the current in passing from one main to the other traverses the lamp or other piece of apparatus. If a diagram of this system were drawn on paper, it would have the appearance of a ladder, the lower end of the sides being connected to the dynamo and the top ends free. The rounds of the ladder would represent the connecting cross wires, each one having a lamp or any other piece of apparatus in its course. Evidently, if the resistance of the large mains represented by the sides of the ladder is very low, the current traversing the cross branches will be virtually

proportional to the resistance of these branches ; and for lamps made to give equal light placed in these branches, the resistances of the latter must be made approximately equal.

The resistance of the 100 volt 8-candlepower glow-lamp, most commonly in use at the present time, is about 300 times greater than that of the mains and branches leading to it. Consequently, if the flow and the return wire of such a lamp were to come in contact before reaching it, what is termed a "short circuit" would result, since the electric current, like steam and water will flow in the direction of least resistance. In the case imagined the current would pass from one main to the other with practically no current travelling through the lamp. In this event the wires leading to the lamp will pass at least 150 times more current than was intended, which would raise these wires to a white heat, or even fuse them if no safety fuse is inserted in the circuit. If a safety fuse does exist, the fusible wire will melt and no mischief be done.

In practice, 1-horse power will produce 1,000-candle power in an arc light ; but an increase in the horse-power gives a far larger corresponding increase of light. For instance, 7-horse power will produce as great a light as 15,000 candles or more. But, on the other hand, the light given by the incandescent lamp is directly proportional to the power of production ; and 1-horse power will incandesce about 16 or 18.8-candle-power lamps.

Although electricity was known to the ancient Greeks, the uses to which it might be applied have remained unknown for thousands of years. It was reserved to Ampère, Ohm, Volta, and Faraday, with a few others, to discover the laws which govern this force. The development of the science in its application to the practical needs of human life may be considered to date from the time of Faraday, whose career ended in 1867. In the past fifty years electric science has advanced in a degree probably unequalled by the progress of any other knowledge since the commencement of the world's history. The electric telegraph was discovered in 1837. The transmission of messages across the ocean dates so recently as to be within the memory of persons who can look back to 1858. The electric light can only be considered to have entered the practical stage since 1880; and although the advances during the last few years have been great, still we know that greater achievements are in store for the present and for coming generations.

In the time of Faraday, electricity was regarded as a fluid, or rather as two fluids, one being positive and one negative. Later, this idea was dismissed, in favour of one which may be termed the "mode of motion" of the ether or some other fluid. The discovery of radium has again altered both the older views, tending, however, to confirm in part the earlier one, that electricity is to be regarded as a

fluid or at any rate a *something*, but only a positive fluid, the negative characteristics being brought about by difference of distribution. In the general description given in this introduction, all technicalities depending upon theories are purposely omitted, so as not to confuse the non-technical reader.

It would be possible to speculate to an unlimited degree as to the future of Science, but experience shows that the knowledge of to-day is as nothing compared with that of to-morrow. A few new facts often upset pet theories. We cannot but be reminded of the words spoken by one of the greatest of philosophers that ever lived—Sir Isaac Newton—who is reported to have said, when dying, “I seem only like a boy playing on the seashore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me.”

A theory in science is as necessary for the imperfect mind of man as his want for a religion. In proportion to the higher education of the mind, and consequently its ability to grasp difficult problems with greater ease, so in proportion do theories, and religious dogmas made by man, go further to the background. Neither will probably disappear completely since man is not perfect, but the time is approaching when science and religion will cease to play the game of “The Tug of War.”

## CHAPTER I.

### DESCRIPTION OF CELLS AND THEIR MODE OF EMPLOYMENT.

MORE than eight years have elapsed since the last edition of *Electric Light Installations* was written, the first volume of which deals with accumulators. During this period, Science in all its branches has made great strides, and in this respect Electrical Science has been as much to the fore as any other.

We will, for the moment, examine in what respect this Science has advanced during the last few years. We all know the interest which was produced by the advent of the so-called X rays, and the improvements made in regard to wireless telegraphy, which has brought it near to a practical issue.

Many other important discoveries have been made, but they appealed less to the wonder of the general public.

When we turn to enquire what has been the progress in connection with the subject with which this book deals, and the uses to which electric energy in general can be put for the benefit of mankind, it

will be found no easy matter to see what, if any, real advance has been made from a scientific point of view.

It must not be thought that, by this expression of opinion, electrical matters of a practical kind have remained at a standstill, for this would not be true; but on close examination, the progress which has been made is mainly of a commercial character, rather than the introduction of new principles, *i.e.*, modifications in machinery and apparatus of such a nature as to cheapen the cost of production, and to be more durable in character.

To the purely scientific man, these matters would be regarded as details, but to the nation at large a great deal is involved. Improvements of the nature indicated enable electric energy to be supplied to the public for light, power, and other purposes more cheaply. Electric traction, whether on railways or tramways, becomes a possibility without loss to the investor, and perhaps one of the most important applications of electricity is now applied, on a practical and paying scale, for the production in quantity of many metals, which but a few years ago were regarded as scarce and valuable, not because there was a dearth of material from which such metals could be obtained, but that no means existed for extracting them in a metallic state on an extensive scale commercially.

This new and extended application of electric



energy, together with the coming industry of Carbide manufacture, are not unlikely to greatly influence the future of civilisation.

A moment's reflection will show how important such advance in electrical matters is in regard to the prosperity of the people, enabling manufactories to be erected in places where otherwise they would be impossible, offering facilities to the public to move from point to point with greater freedom, notwithstanding the growth of population, and giving increased accommodation in cities by making basements habitable and healthy.

Here it is only intended to deal with matters concerning Secondary Batteries, this being the subject under consideration, and from the remarks already made, the reader must not expect any references of a startling character, for no accumulator has appeared different in nature to those which were known seventeen years ago.

Many types have been modified for certain ends: for instance, types exist of a lighter build, suitable for supplying current to motors on road carriages. Others of a similar kind are capable of being re-charged at a very rapid rate. Some have appeared also capable of giving a high rate of discharge, though occupying but a very small volume, but in regard to efficiency no step in advance has been made.

In all cases where success has been achieved, lead

and lead salts are employed; consequently the electrical factors remain unchanged, for lead is lead all the world over, no matter who the maker may be, or what may be the statements he may place on his prospectus.

Experiment has shown that the capacity of plates in a cell varies with the rate of charge and discharge, and to-day there are many industrial and other uses for the accumulator, where this property comes to the fore, more especially in electric central stations which use a secondary battery for the hours of small output, for tramway work, for road carriages, and for portable cells used with induction coils, for theatrical purposes, and a variety of other wants.

The main characteristics of the property referred to are the following: If the plates are rapidly charged or discharged, the capacity will be less than if these processes were done more slowly. The rapidity of charge and discharge varies in some definite proportion with the capacity, which varies with the make of plate. It may therefore be observed that in all cases where heavy discharges are required for a short time, and no very large capacity is necessary, what might appear to be a disadvantage no longer exists, and to obtain a given high discharge, a much smaller area of plate is required, consequently a much lighter battery can be used, than if a battery were employed with a maximum capacity for a given discharge. This is also true for the charging of the battery.

To show the practical value of what has just been stated, the following two or three cases may be given as instances:—

For road carriages, at the moment of starting, or when mounting a hill, the accumulator can be made to discharge at say double the normal rate for short periods. Hence the load of a battery of double the weight is avoided.

The portable cells now so largely used in connection with X-ray work, gives heavy discharges for short periods, with a battery which can easily be carried by hand.

On the stage, effects of great splendour can be produced, with but a small weight of accumulators, portable in character.

It might be thought that to use a battery in this manner would end in the rapid destruction of the plates, and such a conclusion would be correct unless the plates were constructed in a suitable manner. It will be remembered that charges or discharges too high for the size of the plate, produce buckling, the paste to fall out (where this exists), and even in some cases the disintegration of the plate itself.

If therefore a plate can be found sufficiently spongy in character, and of such a build that rapid expansion and contraction in any direction will not deform it, and if pasted will not allow the material to be loosened, and lastly, that the section is so built up that the resistance between all portions of adjoining

plates is practically equal, then there should be, and there is, no reason why the charging and discharging currents should not be greatly in excess of those formerly in vogue. In other words, a given "section" will do the work in a given period of one twice or three times the size, but the total amount of work such a section would do is far less than if treated for its maximum capacity. In fact, the charging and discharging current, if suitable plates are employed, may be increased in theory to an almost unlimited extent; in practice, however, the limit is reached at a comparatively early stage, chiefly owing to the internal resistance of the cell.

It will therefore be found that all accumulators which have been made in recent times, for heavy charges and discharges, have introduced into them modifications, firstly, to allow free expansion and contraction of the plates to prevent deformation; secondly, the introduction of methods to reduce as far as possible the internal resistance; and thirdly, details for equalising the resistance between every portion of the surfaces of adjoining plates.

Various methods have been devised to obtain the first result, which can be better effected in the Planté type of plate, and all devices are made with a view to permitting free expansion and contraction. The method consists in building up the grid in such a manner, that all portions should be as free from restraint as possible in all directions.

The second object in view is best attained by the employment of good conducting metals for the framework of the grid, and by reducing the distance between plate and plate. Neither of these methods are good in practice. Troubles almost invariably follow when the grid is built up of two metals, for although suitable metals exist, their cost is too high. Attempts to bring the plates too close together often end in disaster, even when thin separators are employed.

Lastly, to equalise the resistance between adjoining plate surfaces at all points, is the one desired end which can be obtained with an approach to perfection without trouble or expense.

It may be noted that when a high charge or discharge is sought, the plates are almost universally made very thin, and consequently less robust in character than the ordinary type. The porocity can be better obtained in this manner on the one hand, and lightness on the other, which is so essential in nine cases out of ten, where this class of battery is employed.

For traction it is demanded that accumulators shall be light, cheap to maintain, possess good capacity, bear great strains for short or moderate periods, and be capable of very rapid charging. To meet these requirements, the weight of opinion at the present time is entirely in favour of the Planté type of plate, at least for the positives, by the use of which, all the

above named desirable ends can be obtained, with one possible exception: that of cheap maintenance.

Although this latter quality is claimed by many manufacturers, it is very doubtful whether the statements can be relied upon, if only for the simple reason that experience with this special kind of battery is very limited in point of time.

An accumulator can be obtained to-day from almost any maker which weighs half or a third of a battery, equal in capacity, when used normally, of the heavy type employed for stationary work, and the charging and discharging can be effected in two or three hours, instead of in ten, without apparent injury to the plates. The maintenance is generally placed at ten per cent. per annum. Indeed, the writer believes that some firms guarantee maintenance at this rate. Notwithstanding, much importance cannot be attached to this fact, for guarantees of this nature may be given with a view to an advertisement and joined with onerous conditions.

In any case, the Author's personal experience is not favourable to the life of light cells when employed in road work, and his view, which is not of recent date, has been confirmed by some leading makers of tricycles and light road carriages, in which accumulators were employed for the ignition portion of the gas motor, since many have abandoned the accumulator in favour of primary cells on the ground that the vibration disintegrated the plates.

It must not for one moment be thought that because it is doubtful whether any form of plate to-day will stand such rough usage over long periods, that one may not be forthcoming sooner or later.

The reader must never lose sight of the fact that with batteries such as here referred to, the capacity is far less than in the ordinary heavy type, from the nature of the work they are put to. Consequently, when the battery is stated to be a half or a third less in weight than the stationary forms, it must also be accepted concurrently, that when heavy currents are called for, its capacity will be proportionately less.

To better realise how this applies in practice,—If an electric carriage is employed in a very hilly district where the battery would be called upon very frequently or continuously to put forth its maximum powers, the distance covered would be small, and such vehicles would compare unfavourably with motive power of some other kind. On the other hand, in a locality fairly level in character, where the accumulator would not be strained, its capacity in consequence would be two or three-fold greater, and very considerable distances could be covered before re-charging becomes necessary. It will therefore be seen that the statements of makers, such as, for instance, “one-third the ordinary weight per horse power,” etc., are no guide to the purchaser, since the nature of the district to be traversed has to be taken into account.

It is the fashion of the present day to seek in

electricity a cure for all evils, and we find its employment in many instances where other agencies could be used with greater advantage. It therefore behoves the intelligent man to distinguish between cases where electric energy can be employed with advantage, and where it cannot. To give an example, the favourite form of phonograph is run by a motor, whereas a clock-work movement answers equally well.

For working induction coils, in connection with X-ray and other work, for electric clocks, and endless other purposes, electric energy can be usefully employed, and the portable battery finds a large place, especially when moderate voltages are required.

The "solid" section is an innovation which has recently appeared in a practical form. It holds the same place amongst secondary cells as does the dry battery amongst the primary. The short circuiting of plates becomes an impossibility in this type, but the internal resistance is rather higher.

Nothing is in sight for the construction of a light accumulator of a really satisfactory character, and the writer believes that this may only appear when a new, cheap and light metal is forthcoming, possessed of suitable electrical, chemical, and mechanical qualities not found in the metals within commercial reach at the present time.

In consequence of the greatly extended use of small accumulators at the present time, descriptions



of the leading forms will now be given after dealing with the heavy types.

This is intended to be a practical work, and therefore no attempt is made at literary style. The object of the book is simply to place before the reader a plain and straightforward statement of facts; to treat the whole matter in as concise and clear a manner as possible, and to make suggestions where improvement appears desirable. Without further introduction, the reader will now be invited to consider the subject in what seems to be the natural order. Its treatment proceeds on the assumption that the reader of this little book has a general knowledge of electric lighting, and, consequently, minute details are not given here.

A cell, in its true sense, is the receptacle for the liquid and plates; but, generally, the word is employed to signify the vessel with contents complete, unless by the context the contrary be indicated. A number of cells connected together form a battery; and this, when a secondary one, is generally termed an accumulator. In order to obtain the positive and negative elements every cell must contain two or more plates. All those of the same denomination in a cell are metallically joined together, but the dissimilar plates are not in contact one with the others inside the cell nor outside when the cell is not in use. The current inside the cell passes from plate to plate through the electrolyte, and outside by joining one

set of plates to the other through a conductor, which may be very complex; such, for example, as a long length of wire, with one or more lamps in its course. In this condition, the circuit is said to be closed; and if the plates are not exhausted, a current flows. When the outside conductor is broken, no current passes; and the circuit is open. The only object in employing a number of plates of each kind, instead of one positive and one negative, is to obtain a low internal resistance without the inconvenience of using very large single plates.

Cells are of two kinds—primary and secondary. The primary cells are made in as many ways as there are stars in the sky, but all have one characteristic, namely—that when exhausted the whole or part of the chemicals employed must be renewed, and in most cases the plates also. For practical electric-lighting purposes such cells are of no value, notwithstanding the assertion of many makers to the contrary. It must not, however, be supposed that a good primary battery may not one day be forthcoming, for it is quite within the bounds of possibility.

The other cells are termed secondary, because they may, without the putting in of fresh chemicals, be revived by simply passing a current through them. These have been very appropriately termed by Mr. Fitzgerald reversible cells.

Until the introduction of secondary batteries the Bunsen battery was almost exclusively employed for

obtaining large currents ; but it never did, and never could have, become a battery for popular use, because of the corrosive nature of the chemicals, the poisonous fumes given off when a current was taken, and the necessity for continual replenishment. For the telegraph, domestic use, electric bells, laboratory testing, and many other purposes, the Leclanché cell has been used to a vast extent, chiefly on account of the harmless chemicals employed and the long periods of time during which the cell would work without being re-charged. The Leclanché cell may be regarded as having been completely superseded by the dry cells, which, although not new, have recently been subjected to great improvements, the Gaussner cell having led the way, so that they may no longer be classed with toys.

Many types of dry cells are, when exhausted, capable of being restored by passing a current through them. Thus they are placed in the same category with the secondary batteries, and since they contain no liquid they are clean in use and are not liable to the many disadvantages well known to exist in cells that contain fluid. Besides these advantages, dry cells possess all that can be claimed for the Leclanché cell, and may readily be employed in connection with small lamps, for night lights and the like.

It may, therefore, be concluded that one of the great advances of the present day has been the

discovery of batteries that are reversible and free from the many objections so common in older forms for large currents as well as for small.

It has become a practice amongst makers of secondary batteries to call the true positives the negative plates and *vice versa*. Therefore, not to cause confusion, the manufacturers' designations will be adhered to throughout this book. And it may be further remarked that scientific men have generally adhered to this rule.

The cells proper are made of glass, metal, or celluloid, and frequently of wood lined with glass, lead, pitch, or celluloid. For stationary work, glass is by far the best, unless of very large size; but for movable batteries, such as are used in launches, motor-cars, and tramcars, other materials must be chosen.

The fluids, or electrolytes, are very numerous. They may be alkaline, acid, or neutral, according to the plates employed and other considerations.

The plates may be all metallic, or one set may be of metal and the other of carbon, or any suitable substance. In some cases neither the one nor the other is composed of metal.

To attempt a description of every existing secondary cell would be of little interest in a book written solely for practical purposes, since there are but two sorts of cells which are of real value at the present time. In the one, the plates are composed

of chemically treated spongy or strips of porous lead; and in the other, the lead plates (or some alloy of lead) are perforated, and the holes are filled with lead compounds. Of both types numerous modifications are employed to obtain the same end. There is a third type, where lead plates are used in conjunction with zinc ones, the latter taking the place of the negatives; but such cells cannot be reversed an indefinite number of times, owing to the fact that the zinc plates do not, at each reversal, retain their original form, also to the growth of zinc-trees and local action. They must, therefore, be excluded for electric-lighting purposes on a large scale. These cells, however, are useful for portable lamps and laboratory work, being of comparatively light weight for the energy they contain. Thus there are two types which require to be considered and described.

Those who are anxious to study other kinds of cells should refer to Mr. Berly's translation of M. Emile Reynier's treatise on "Accumulators," published by Messrs. Spon & Co., of London, and other analogous works.

Cells of the plain lead type were shown to be reversible first by Planté, although earlier workers are said to have previously discovered this property. To Faure appears to belong the merit of having so modified the Planté cell as to make it a practical one; in fact, those now so largely used are but Faure cells improved.

There has been considerable discussion as to whether Faure was, or was not, the discoverer and patentee of the method of making pasted plates. It is not proposed to discuss the question here, but it may be of interest to many readers to know that Mr. Pulvermacher, in a patent specification, No. 2062 (1869), used these words: "Another part of my invention consists in employing negative plates of open-work form, as described . . . . so as to form constant elements by means of insoluble metallic salts capable of electrolysis and of depolarising action on the negative part of the elements, such as sulphate of lead, bi-sulphate of mercury, or chloride of silver." The claim relating to the above is as follows: "13th.—The employment of metallic salts, as before described, in plates or cores, in a way adherent to the metallic surfaces." The negative plates spoken of in the above are those now termed positive. This patent was taken out also in the United States. It would therefore appear that Pulvermacher anticipated Faure.

The chief aim of all improvements in the lead-plate type is to make the plates porous, yet strong, so as to offer as large a surface as possible to the electrolyte.

The perforated type may be termed pasted plates. The holes are filled with paste made by mixing red lead with sulphuric acid for the positive, thus eventually forming lead sulphate, the negative paste being

made of litharge mixed with sulphuric acid. The acid and paste frequently have a small proportion of other chemicals mixed with them to produce three results: (1) beter adherence between the paste and the metal; (2) a harder paste; (3) to enable a more rapid formation.

In cells of this kind, those of the Planté type (as well as in cases where zinc plates are used to replace the negatives), dilute sulphuric acid is employed for the electrolyte.

The chemical action is the same for both types of plates, and may be explained generally by saying that when the cells are charged, more oxygen exists in the positive, and probably more hydrogen in the negative plates, than when discharged. Without giving a detailed account, a few words on the subject of their manufacture may prove of interest.

First, let us take those of the Planté type. There are many makers of this kind of cell, each of whom has a different method of rendering the lead plates porous. Some cast them porous to start with, others build them up of lead ribbon, and most treat the plates with nitric or some other acid before they are formed. In all cases the same end is in view, viz., porosity. The positive and negative plates may be chemically identical before they are placed in the cells. They have tail-pieces (termed by the manufacturers "lugs"), either cast on them or put on afterwards, for the purpose of connecting the plates

together. A strip of lead is then soldered to the lugs of all the positives, and the same is done with the negatives destined for one cell. The two sets of plates are pushed into one another, so that the positive and negative alternate, thus forming a compact block, every plate being insulated from the next one by some non-conductor, called a separator; but each set remains joined by the lead strips described above. Such a block of plates is then firmly held together by rubber bands; or by wooden frames, the wood having been boiled in paraffin wax; or by the more recent method of strips of ebonite, vulcanite, or glass; and frequently nothing is employed. The whole is termed a "section," which is then ready for "forming." This process consists in passing an electric current, for a long period, through the cell. In practice a large number are coupled together in series to undergo the process. The result is that, though positive and negative plates are identical, after a time their chemical composition is so altered that their similarity no longer exists, and they become capable of retaining a charge: which means, scientifically, that a good primary battery is made with reversible properties. In order that a good retaining charge may be obtained, in some types frequent reversals are necessary. So many improvements have been made in these plates, that any reversals which may be required are now done at the manufacturer's works, so that this troublesome process need not be



performed after the battery is erected on the spot where it is to be used. Indeed reversals are rarely necessary in the most recent makes. The reversal is accomplished by completely discharging the cells through a resistance. They are then charged the reverse way; and, to complete the operation, another discharge must be given, followed by a re-charge in the original direction.

When the sections are very large, they have to be built up in a somewhat different manner to that described, which will be referred to later on.

One point in favour of the plain lead type of plate is that a very large charging current, or rapid discharge, does not appear to injure the plates, which may be the case with the pasted type. Such a battery is, therefore, very suitable for regulating the light and for short heavy discharges. It, therefore, has been introduced into many public electric supply stations, and is gradually coming into favour with private users.

A few years ago, Messrs. Elwell-Parker (now Messrs. Parker) supplied many batteries of this type, but soon abandoned their manufacture in favour of the pasted kind. Plain lead plate batteries were also employed in the experimental lighting of the town of Colchester (the plates being built up with lead ribbon) which attempt ended in failure. The company is no longer in existence.

The plain lead type of plate has been so largely

improved that the majority of the failings which attended the earlier forms have now disappeared.

The pasted type, although requiring more care and attention, is still largely in use, but their field has been much encroached upon by the other type.

The rules which should be followed for keeping an accumulator in good order apply equally to every type of cell now made. This should not be forgotten when reading all that follows on this subject, remembering, however, that since the pasted plate is more delicate extra precautions require to be taken.

It may be fairly concluded that all the earlier forms of accumulators are now extinct, and any survivor may be regarded as an exception. Therefore, to describe any make of cell that is not modern would be to enter upon a history of the subject; which is not the intention of the writer of these pages.

Pasted plates are made in a variety of ways, but in all the object is to produce an efficient support (called a grid) of lead, or other suitable material, filled with a paste of a hard and durable character, and having the requisite chemical properties.

The alloy of lead and antimony makes a better plate, being far stronger than lead alone; and it is practically unacted upon by the electrolyte. The plates intended for positives are, as already pointed out, pasted with red lead and sulphuric acid, and those to be used for negatives with litharge and sulphuric acid. In the latter case water would answer the

purpose; but the paste thus obtained would not be so coherent.

The plates are now built up into sections by soldering the lugs of a number of positives to a strip of lead. The negatives are treated in the same way. These two sets of plates are pushed into one another so that the positive and negative alternate, every plate being insulated from the adjoining one by the insertion of separators. The number of plates, of which any section should consist, depends upon the work it has to do.

The number of negative plates always exceeds the positives by one, so that a negative is seen at each end; the object being to utilise the two sides of every positive. It may, therefore, be pointed out that, if a section containing only one positive be required, a negative plate, in order to obtain the best result, should be placed on either side of it. When the end plate is a positive, the chemical action upon its two sides is unequal, and the plate frequently buckles in consequence, which is not likely to occur with a negative plate. Only the edges are visible, the plates being about a quarter of an inch apart. There is no connection between the positives except through the leaden strip at the end of the lugs, this being left long enough to join to the next cell; and the ends of the lugs, with the strip, remain above the liquid in the cell. These remarks also apply to the negatives. The section is now ready for forming, that is

to say, to receive a charging current for a long period, so that the plates may be chemically charged to retain a charge, or, in other words, have capacity.

The balance of good and evil, in regard to plates being placed further apart, is simply a matter of internal resistance, the distance may be increased to say half an inch before the internal resistance becomes too high for practical purposes.

Those who have used primary batteries know only too well how zinc plates eat away near the surface of the liquid. This is due to the increased electric action, *i.e.*, current density, at the upper part of the plates. The reason may be thus explained. It may be assumed that the current starts from every part of the plate to the outside circuit, and consequently the current starting at the upper parts of the plate will travel through a less resistance than that starting at the lower parts; in other words, the chemical action will be more vigorous near the surface of the liquid. A similar action takes place in secondary batteries, which in practice shows itself by the plates becoming more quickly charged and discharged near the upper portions than the lower. As a consequence, for rapid discharges some method must be devised of making the resistance between the upper and lower portions of the plates as small as possible. This can be accomplished in a variety of ways, *viz.*, by having a large quantity of conducting metal along the perpendicular edges of the plate, or by making the grid

itself massive, or by having additional conductors to the bottom of the plate, so that the charging and discharging currents may enter and leave the plate simultaneously near the top and at the bottom.

The strips connected with the plate lugs may be used in common for two sections, in order to reduce resistance, and for cells from which very high discharges are demanded, the plan is good. But as a rule it is desirable to keep to the customary practice of connecting the cells together by strips, and for two reasons: in order (1) that the pots may be so placed that the edges of the plates may be seen, so that paste or scale sticking between the plates, or buckling, can readily be observed and immediately remedied; and (2) that the sections may be more easily removed from the pots at any time. The owner of the battery must, therefore, decide, according to the nature of the surrounding circumstances, which method of connecting up is the best.

Wherever wood is employed as a constructive part of a section, the author prefers to substitute ebonite; and at Broomhill this material has been introduced in all such cases, the extra expense being approximately ten shillings per cell; an outlay which has only to be incurred once, because the ebonite can be used over and over again. The objection against the use of wood in the electrolyte is more sentimental than real, for if this material has been thoroughly saturated with a hydrocarbon, the electro-

lyte does not attack it, and consequently it does not become a conductor. Pieces of wood so treated are in the author's possession; they have been in the acid solution many years, and show no trace of deterioration or tendency to conduct. He, therefore, is satisfied that there are no grounds for the objections taken, provided that the wood has been thoroughly prepared. Yet, for neatness of appearance, ebonite is the best, and never deteriorates. Celluloid is a good substitute for ebonite or wood.

To prepare the sections for forming, they are put in their pots, and dilute sulphuric acid is poured into each cell till the level is at least half an inch above the plates. The cells are now connected in series, and a current is passed through them for a long period, causing the paste on the positives to become converted into lead dioxide; but the conversion is not complete, as will be explained later, and the paste on the negatives becomes partially reduced to finely divided lead. This process having been gone through, the sections are said to be formed, *i.e.*, ready for use. More will hereafter be said on this point.

For plain lead positive plates the forming process is the same, but here it is the lead which is transformed into the dioxide.

With regard to charging and discharging, it will be shown in a future chapter that the whole process is a sulphating one. When the paste upon the plates

is in such a condition that only with difficulty can it be reduced to peroxide of lead, it is usual to describe the plates as being badly sulphated. Therefore, when the plates are said to be "sulphated," this is an abbreviated expression for deleterious sulphating. The term "fully charged" must be taken to imply that it is charged sufficiently for practical purposes. The chemical process is the same for lead plates of any type.

The positives may be distinguished from the negatives by their colour, which is variously termed plum, chocolate, red, and dark red. The negatives have a greyish tint on the surface, and the colour of wet slate at their edges.

Whatever may be the type of cells used, care is always necessary, though, at the same time, an intelligent man, guided by a competent teacher, will soon learn for himself what should be done on all occasions likely to arise; and, with proper attention, the troubles which so many persons encounter would never occur.

Every section with lead plates, no matter of what type, unless exhausted, gives a pressure of 2 volts as near as possible. Thus one cell is valueless for lighting purposes, because pressures from 50 to 100 volts are required for practical use. At the present day the pressure of 100 volts is universal for private incandescent lighting, any other pressure being quite the exception. Consequently, an accumulator con-

sists, in a majority of cases, of 50 cells, or of two or three more than this number, so as to allow a few extra for reserve.

The cells are connected with one another by joining the leaden strip, uniting the positive plates in one cell, with the strip connecting the negatives in the next one, and so on, or in some equivalent manner. They are then said to be connected in series. The strips may be joined by solder, by bolts and nuts, or by clamps.

Cells can also be connected in parallel, whereby two or more may be made to act as a larger one of twice or more times the capacity of the single one (*i.e.*, if all are of equal size); but the E.M.F. will be that of one cell only. Cells of unequal size may be coupled in like manner. Again, cells may be connected first in parallel, then in series. It is also clear that more complex arrangements are possible, such as cells in series placed in parallel and then again placed in series. All combinations have their uses, under special conditions; but, in practice, it is always better to choose the simplest combinations.

To give an instance: suppose in an installation requiring 100 volts the cells intended to be employed will only have half the capacity required, or give only the deserved discharge, then if 54 cells give the pressure wanted, including the spare cells, it is evident the cells must be increased to 108 in number, which may be coupled in one or two ways for giving



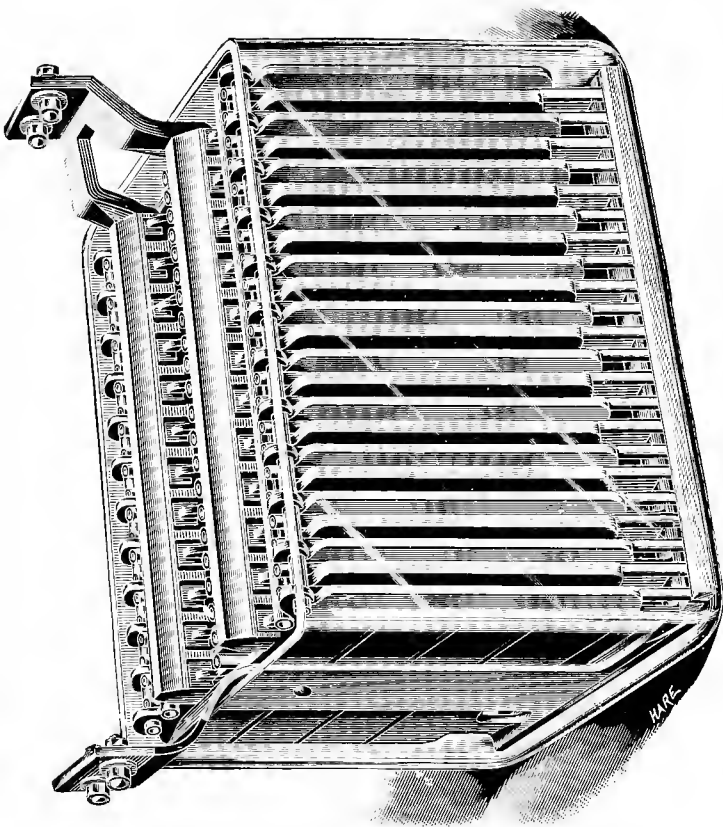


FIG. 1.—23-PLATE F.P.S. CELL IN GLASS BOX.



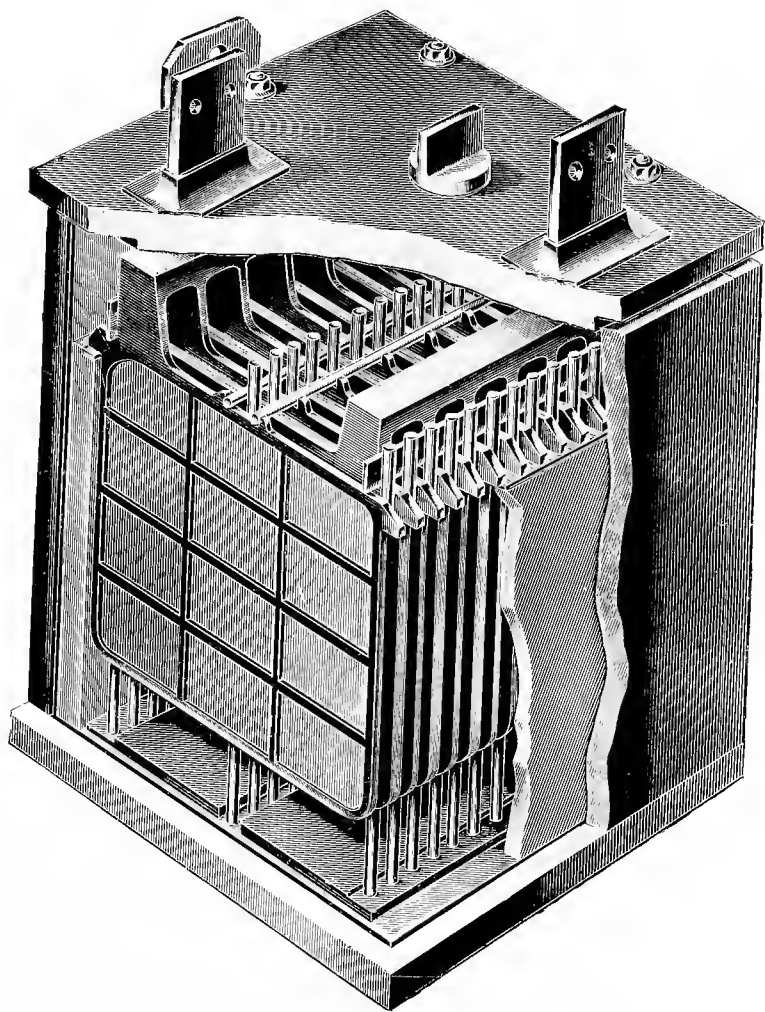


FIG. 2.—17-PLATE E.P.S. WT TYPE CELL IN WOOD  
LEAD-LINED BOX.



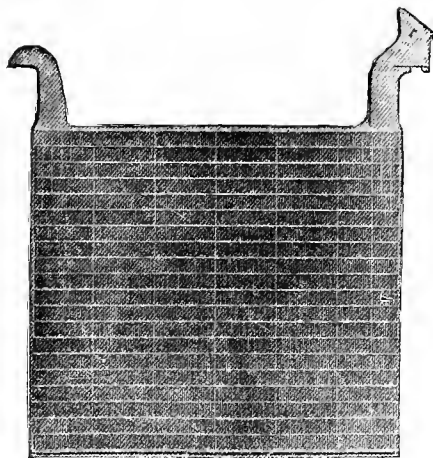


FIG. 3.—TUDOR POSITIVE PLATE.

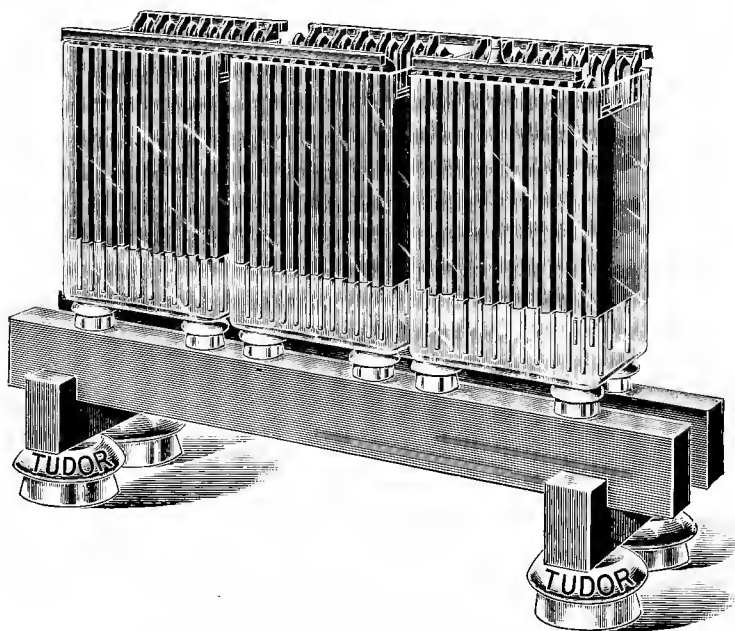


FIG. 4.—THREE TUDOR CELLS.



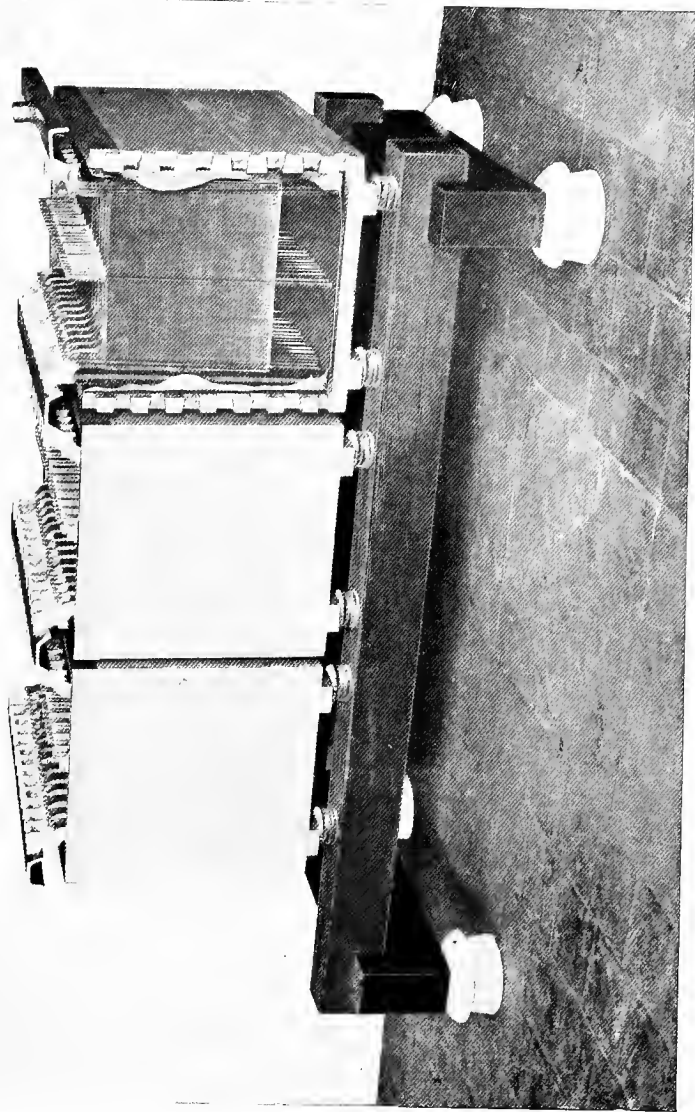
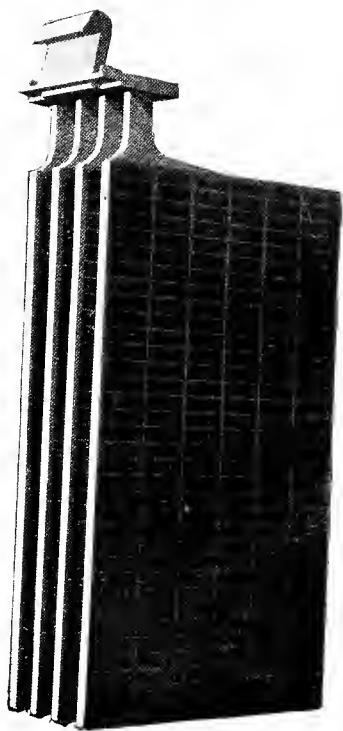


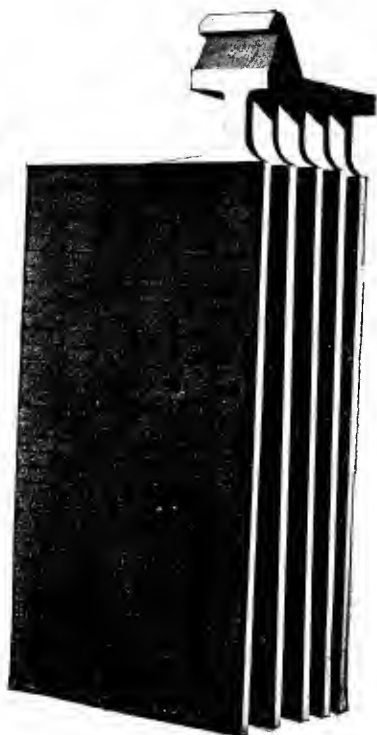
FIG. 5.—TUDOR CELLS IN LEAD-LINED WOOD BOXES.







POSITIVE GROUP.



NEGATIVE GROUP

FIG. 6.—CHLORIDE PLATES.



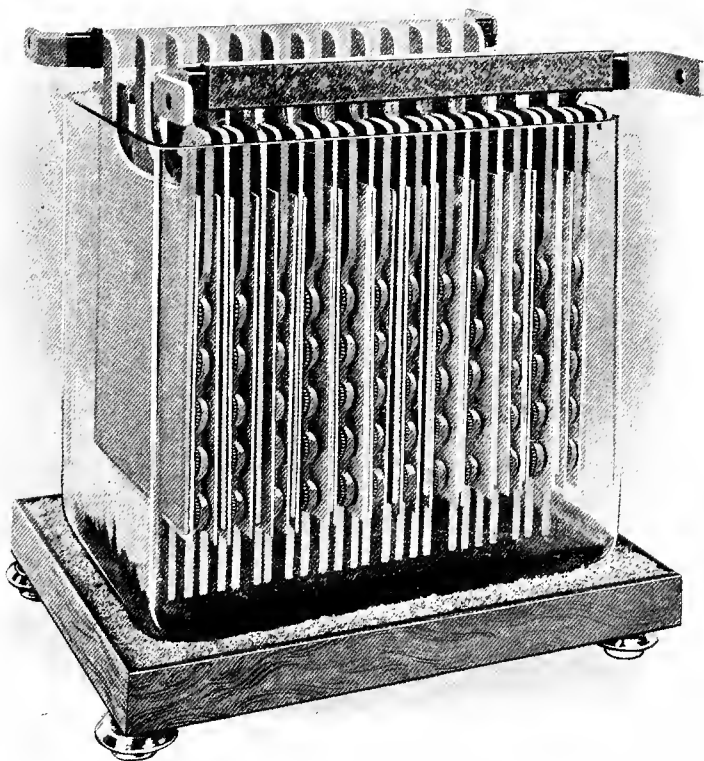


FIG. 7.—CHLORIDE COMPLETE CELL.



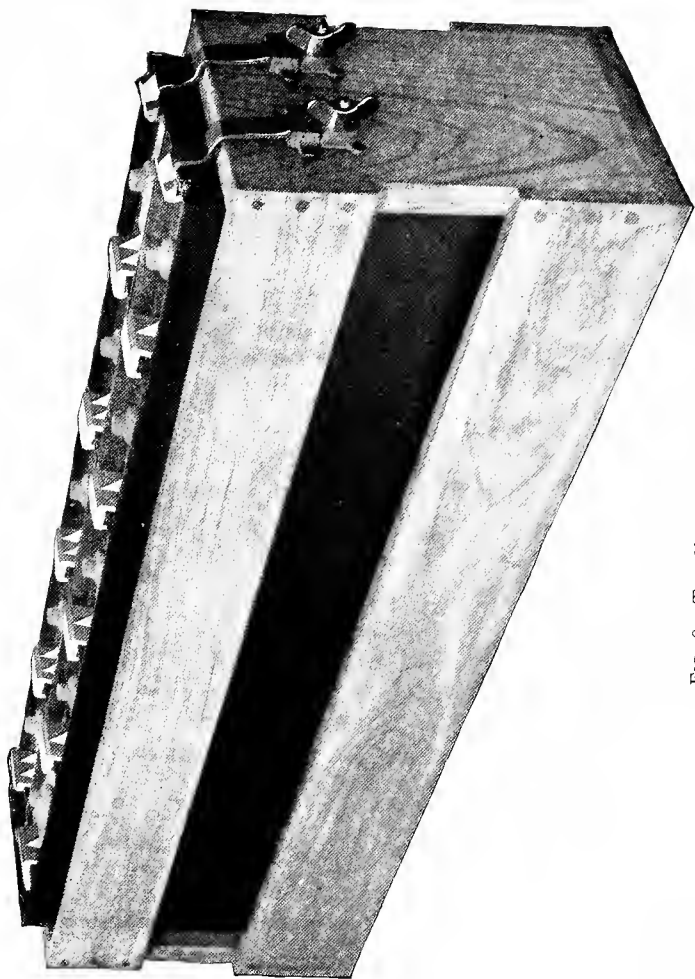
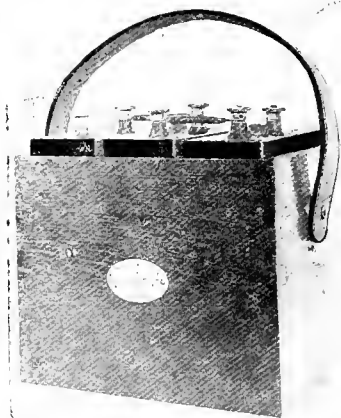


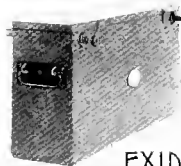
FIG. 8.—TEN EXIDE CELLS IN CRATE.





EXIDE CELLS

in teak container with lid



EXIDE CELLS

in teak container with lid

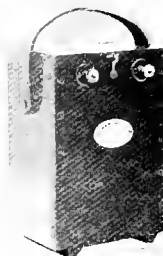


FIG. 9.—SMALL EXIDE CELLS.

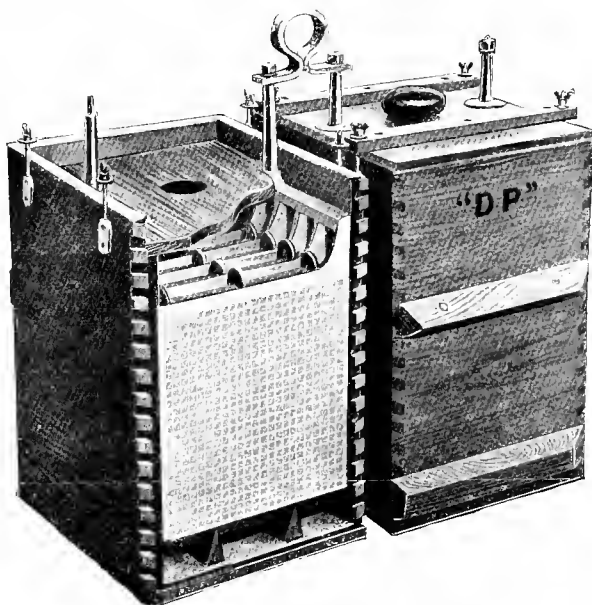


FIG. 10.—D.P. PORTABLE CELLS.





the required result. One way is by coupling these cells two and two together, thus: the positives and negatives of two cells are joined together by their connecting strips, positive to positive and negative to negative; these two cells are then treated as one cell, the positive at one end being joined to the negative of the next couple, and so on. Another way is to arrange the 108 cells as two complete batteries of 54 in series, then to join the positive ends of these two batteries together, and also the negative ends, this method being termed "two batteries placed in parallel." When cells are placed two and two, if the pressure of any two so coupled differs ever so little, from any cause whatever (and, in practice, the pressure of no two cells is the same), it is evident that the one which has the greater pressure will discharge into the other which has the less, the practical result being that a battery, made up on this system, will get out of order in a very short time. This method may, therefore, be discarded as an impracticable one; whereas, if two batteries are connected in parallel, the sum of the pressures of the cells in each battery will be found to be virtually equal. If any variation exists, the difference in pressure (assuming that all the cells are in good order) will be so small that any current flowing from one battery to the other will be almost inappreciable; consequently, the battery runs no risk of being injured.

Another advantage exists in the use of the parallel

battery method. If a glass pot in a single battery were to break and the electrolyte to escape, it is clear that the circuit would be cut and all lamps supplied by the battery extinguished, if the dynamo is not running. Should, however, the dynamo be running, it is almost certain that every lamp in use at the time would be destroyed. But the probability of a cell breaking at the same time, in each of the two batteries placed in parallel, is very remote; so that an accident arising from one glass cell breaking would produce no inconvenience. Besides, an opportunity is given at any moment to change, repair, or clean, one battery, leaving the second to supply the light. The breaking of a glass pot happened on one occasion in the author's installation, when the value of two batteries in parallel was proved. Any number of batteries may be placed in parallel according to the requirements of the case, thus an easy method for increasing the capacity of an installation is always present.

Since each battery circuit must have an ammeter, it is clear that so long as the readings of these instruments are the same, the batteries are in good order. Whereas if they vary it is a proof that the E.M.F.'s of the batteries differ, and something is wrong. In this manner a good and simple check is always present.

There is another way of obtaining some of the advantages derived from the use of batteries in parallel: the method is that of placing two or more sections in one pot, and connecting them together in

parallel. Thus a section may be removed for any purpose without breaking the circuit. This system is more suitable for public than for private installations, because each cell becomes very heavy and large. The parallel battery system on balance is the best, when all points are considered.

The methods of using and coupling batteries in parallel are dealt with in Volume III. of *Electric Light Installations* by the author.

The detailed description of some leading types of cells may now be proceeded with, dealing first with the heavy types then with the portable class.

The oldest firm in England to make secondary batteries is the Electrical Power Storage Company, whose wares are known by the initials E.P.S.

The E.P.S. cells have been improved from time to time to keep pace with the fresh demands made daily in respect to these batteries.

At the present time this firm, in common with nearly every manufacturer of the present day, for large cells, adopt glass tubes for separators, give more space between lower edges of the plates and bottom of pots, make the plates thicker, greater space between the plates, and heavier connecting strips. The plates are of the formed lead type.

Fig. 1 gives a good view of a large cell in a glass box, and Fig. 2 shows a section in a lead-lined wooden box suitable for motor-boats, motor-cars, and other portable work.

These sections may be discharged at high rates in accordance with rules mentioned in the chapter on charging.

One of the earliest foreign firms who manufactured with success, and whose produce is found largely in England, is the Tudor Accumulator Company.

The positive plates are  $\frac{1}{2}$  inch thick and cast in thin vertical ribs, with thick horizontal ribs at intervals for giving strength. The total area equals 10 times the surface of the smooth plate. These plates are formed. Fig. 3 gives a good idea of the pattern. The negative plate is parted in squares in a lead grid.

Three cells connected together are shown in Fig. 4. It will be noticed the modern type of building the sections exist, namely, with glass tube separators. Another view showing better the method of the section build is seen in Fig. 5. Here the plates being heavy they are supported by hanging on the edges of the lead-lined wooden boxes. These plates may also be used for very heavy discharges.

Another cell, a favourite with many, is the one made by the Chloride Electrical Storage Company. The positive plate is cast under pressure in an alloy of lead and antimony. The holes in the grid are cast countersunk on both sides. The holes are then filled with lead tape, being pressed in under a pressure of 8000 lbs. per square inch; 3000 such "rosettes" can be put in per hour per machine.

The plates are finally submitted to a pressure of 200 tons before going into the forming bath.

The negative plate consists of pastilles of fused chloride of lead with a small percentage of zinc, and cast into the lead grid.

There is also another type of positive grid, termed by the company Exide, which consists of thin vertical ribs strengthened at places by small triangular bars, the whole surface being flush. These connecting bars are "staggered" and the plate is finally pasted. The positives and negatives are then formed. The positive plates are now ready to be cast together for sections.

The negatives are now placed in a solution of chloride of zinc, with alternate sheets of zinc between them and short-circuited. Chlorine gas is evolved. They are then washed in water and given a hydrogen bath to remove all traces of chlorine.

These plates are now cast together on strips, the sections built up, and all is now ready for use. The separators are of pierced wood, forming a complete diaphragm between the plates.

Fig. 6 shows a section of chloride plates pulled apart, and Fig. 7 a complete cell. Fig. 8 illustrates a portable Exide battery, and Fig. 9 small Exide cells.

We now come to the produce of the D.P. Battery Company. The author has used these sections for over 14 years, and the sections are still in first-class condition. Their management has been well

attended to throughout that period, and they have done hard work during the time.

The positives are of formed lead, and the negatives are pasted. The Company make two types of positive plate—one built up in lead strips (see Fig. 11), which is shown on the bottom block. (*N.B.*—It is best to have a third support in centre.)

Fig. 12 shows the negative plate on right-hand side, the left-hand view being a piece of the unpasted negative enlarged. Fig. 13 illustrates two complete cells with positives of the strip type.

The heavier type is known by the name of Lumford heavy and Lumford light types. The grid of positive is shown in Fig. 14, also the section, and the negative plate and section in Fig. 15. The only difference between the heavy and light types is in the weight of the plates, due to their thickness.

Fig. 16 shows two Lumford cells in glass pots; these plates hang on the glass cell edges.

For portable work the cells shown in Fig. 10 are used.

The replacing of a plate is a simple matter in all these types, but the author has never been called upon to renew a plate owing to the perfect working of his batteries.

An excellent way to form holes in a grid which shall be smaller at the surface than inside, and better than the process of burring over the edges of cylindrical holes, is the following method:—It is

well known that if a plate of metal containing holes, truly drilled or punched, is rolled under pressure so as to reduce its thickness, these holes become barrel-shaped, the smallest ends being at the surface of the plate. Consequently, the rolling process and the burring process apparently attain the same result. But there is one important distinction: with surface contraction, obtained by rolling, the plug of paste is wedge-shaped; whereas with the burring such is not the case. And experience has shown that this burring process will not secure the paste from falling out, if the cells are badly used; but from experiments made by the author it appears that the plugs keep in place, under all conditions with the rolling process. However, plates which have been burred possess at least one advantage, viz. that of securing the paste in place during transport and rough usage.

Many attempts have been made to obtain a solid or semi-solid electrolyte. Plaster of Paris, sawdust, various jellies, flannel and other materials have been employed. A section has appeared recently devised by Mr. Niblett, which approaches the solid section. Its resistance is slightly higher than in the case of a liquid electrolyte. With this new section short circuiting and buckling is practically impossible.

The Niblett cell stands by itself, and is coming largely into use. Hence a brief description of this cell is necessary. There are no plates, consequently no sections. The outer box is made of lead and

forms the negative element. In this box is placed a porous jar, made of a preparation of asbestos. In the centre of this jar a suitable lead core or rod exists, and it carries a lug at the upper end to be used as the positive element. The inside of the porous pot, and around the central lead rod, is packed with pellets (or small cylinders about  $\frac{5}{16}$  inch in diameter) of oxides of lead and spongy lead. The space between the outside of the jar and lead box is packed with disintegrated lead. Consequently a semi-solid secondary cell is formed, which is exceedingly strong and gives excellent results, and capable of giving heavy discharges when required. Figs. 17 and 18 show the vertical and horizontal sections of one element of this type of cell, and Fig. 19 a complete one containing eight elements. Fig. 20 shows the pellets used in its construction. For ignition batteries on motor cars these batteries are excellent, since they stand any amount of vibration, but for electric cars their weight is a disadvantage. These cells are known by the name of N.S. cells and manufactured at Horton-Kirby, Kent.

Another new form of cell is one brought out by Messrs. Peto & Radford. Here a white lead sulphate mixed with dilute sulphuric acid, fills the pot and all spaces between the plates. It is claimed that no deleterious sulphating can result under any conditions, and the cell approaches the dry primary cell for advantages of transport.



A few words respecting small portable batteries and cells must not be overlooked, seeing that these are much used in the present day for various household purposes, apart from their constant requirement for X-ray work, the ignition apparatus in a large class of motor cars, and for other work. The makers of these small types are unlimited, and since all are practically of the two types already spoken of, there is no need to describe them afresh. In France the Tudor and Dinin cells are largely in use. These two classes of cells and those of Messrs. Peto & Radford (known in France as "Compound") are extensively employed. A more detailed description of the latter will therefore meet all purposes. This firm makes two kinds of positive plates, viz. the ordinary and the armoured. Fig. 21 shows two celluloid pots joined together containing sections with ordinary positives. Fig. 22 shows a Peto-Radford pair of celluloid cells joined together with both positive and negative plates armoured. Fig. 23 illustrates a single armoured plate; it will be observed that the pasted plate is pushed into a skeleton lead envelope, on each side is a perforated piece of ebonite, to prevent the paste falling out by vibration, and crinkled perforated ebonite sheets act as separators between these armoured plates. These cells give excellent results. To give the reader some notion of what these small accumulators will do, it may be stated that a 4-volt

armoured battery of 12 ampere hours' capacity weighs complete  $5\frac{3}{4}$  lbs. The charging rate is  $1\frac{3}{4}$  amperes for 10 hours, and is capable of supplying the electric ignition apparatus of a single cylinder motor-car for a distance of 600 miles. These cells are made as large as 100 ampere hour capacity. They also have lead terminals.

In small batteries there is often a difficulty in keeping the terminals clean and insulated. Messrs. Peto & Radford, to meet this trouble, have brought out a simple form of nut made of ebonite. This is shown in Fig. 24. The usual milled nut is removed altogether and replaced by the nut inside the ebonite nipple, both of which form one piece, and the leading wire is soldered to this nut. Consequently it is only necessary to exchange the old nut for the new one and joint the wire to the circuit.

Another form of cell is also supplied by the same firm known as the "Cadmium cell," and in France by the name of "Pile Mixte." This cell is and is not an accumulator. The device presents certain advantages, but it is unlikely to come largely into use, for the reason that fresh electrolyte must be put in every time the cell is discharged, and since the liquid is destructive to clothing, many persons would object to going through the process. The construction of the cell is as follows:—Two positive plates are employed and form the outside plates. Between them is the negative plate, which is a pocket of

ordinary lead, neither pasted nor formed. The electrolyte is dilute sulphuric acid, s.g. 1200. The cell is charged in the usual manner, the current being one-tenth of the nominal capacity of the section. In this manner the positive plates are peroxidised. The section cannot be discharged since there is no suitable negative plate. To effect this a pellet, weighing about  $\frac{1}{2}$  oz. of cadmium is dropped into the negative envelope. The cell will now give a discharge of 1 ampere (size of plates usually made) for 3 hours, *i.e.* on continual discharge. So soon as the cadmium is dissolved no more current is obtainable, but more cadmium put into the negative envelope will again renew the section, and so on until the positive plates are discharged. To re-charge the cell it is necessary to throw away the electrolyte and put in fresh, then re-charge in the usual manner. The chief advantages of this cell are, that it may travel with the plates fully charged, and no liquid in the pot; that the amount of discharge can be regulated by the weight of cadmium put in; that when no cadmium is undissolved, a short circuit is of no consequence, since there is no E.M.F., that the voltage of these cells is considerably greater than 2 volts.

Where these or any other form of accumulator is employed for ignition purposes, the time for total discharge may be taken from two to three times that of a continuous discharge.

## CHAPTER II.

### SETTING UP THE CELLS AND THE ACCUMULATOR-HOUSE.

ON their arrival, the pots, whether of glass or other material, should immediately be unpacked and got ready for the sections; for, unless the air is dry, the plates will be injured by exposure. Since glass pots are employed almost universally in stationary work and require the most care, it will be assumed in the following chapters that such cells are used. At the same time it must be borne in mind that many of the recommendations in respect to glass cells may be applied with advantage to those made of other material.

Strong shelves, for the reception of the battery, must be prepared, and small boards on which to place each cell. Every board stands upon porcelain, or glass, insulators; which in certain patterns may be filled with oil, to insure better insulation (see figs. 25 and 26). The glass pots should be placed along

the shelves, and upon the boards which rest on the insulators, leaving about an inch between cell and cell; but they must on no account touch. The purpose of the boards is to prevent the insulators from cracking the glass cells by an unequal distribution of the weight. The boards are frequently made as trays, about half an inch deep and sawdust put in to insure the glass pot taking an equal bearing. The shelves and cell boards should be varnished, for the sake of insulation as well as cleanliness.

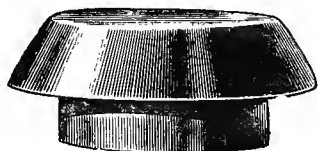


FIG. 25.

OIL INSULATOR. GENERAL VIEW.

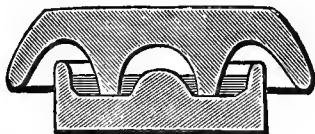


FIG. 26.

OIL INSULATOR. SECTION.

Outside of each cell, and close to the mouth, melted paraffin wax should be applied by means of a brush, so as to form a band about an inch broad. The best way to heat the wax, without burning it, is to melt it in an ordinary glue-pot provided with an exterior water-vessel. The band of wax prevents the liquid from creeping over the top, rendering the outside of the pot wet, and thus impairing the insulation. It is of the highest importance that every cell should be perfectly insulated, in order to avoid waste by leakage. Bad insulation in the accumulator-house may even prove a danger in the dwelling-house.

Each section, or the individual plates intended for one section, is sent out from the factory in a separate box or crate. They must not be handled roughly. When the plates are sent out already built into sections, these must be unpacked without disturbing a single plate, and every particle of packing, straw, hay, or otherwise, must be removed. Any chips, or any bits of paste, which may be found sticking between the plates, should be carefully taken away. A bellows may be used to blow the dust from between the spaces. In fact, the spaces between the plates must be absolutely clear, for future success in the working of the accumulator depends in a great measure on the way in which the sections have been unpacked and freed from rubbish. It is true that straw and wood are good non-conductors, but the action of sulphuric acid upon these substances carbonises them. In that state they have considerable conducting properties, and their presence between the plates would produce leakage. At this stage it is supposed that the pots have been cleaned, the edges waxed, the cells placed in position upon the shelves, and the plates all unpacked.

The sections must now be put into the cells. In a properly appointed accumulator-house this is simple enough; and the arrangements best adapted for the purpose will shortly be described. But the plan to be adopted, where luxuries do not exist, will first be considered. Remove the first glass cell from the

shelf, and place it upon a piece of board laid on the ground. This board should be somewhat narrower than the cell, in order to facilitate the lifting of the latter when the plates are in. The support for the section, consisting in most instances of a skeleton wooden frame paraffin-waxed, is first put in the pot. When such a frame is employed, it must be carefully placed in the proper way, so that the thicker sides of the frame bear the weight of the plates. Observe also that this frame is placed right way up, so that it may take an even bearing upon the bottom of the cell; for, if it does not take an even bearing, the glass will probably be broken by the weight of the section. In order to guard against such an accident in those cases where the wooden frame does not fit the bottom of the pot, wedges of paraffin-waxed wood must be placed beneath the frame, so that the weight may be equally distributed.

Now lift a section clear of the cell; lower it gently till it reaches the bottom and rests fairly upon the frame, taking care to observe that the plates have not shifted, and are quite straight and central in the cell. The section must not touch the sides of the pot, but should have a small clear space all round. Frequently the mouth of the cell is square, but if not, allow the greater space to exist between the edges of the plates and the sides of the vessel, unless the dimensions of the sections are such as not to admit of their being placed in that manner. This

gives room for the acidometer, which is shown in fig. 29. Iron hooks will be found most convenient for lifting the sections from the packing-cases, and then putting them in the cells. In most cases two men are required for this purpose, the sections being very heavy. The hooks consist of a piece of iron wire, about a quarter of an inch diameter, formed in the shape of the letter U; the free extremities are again bent into hooks, each half circle being about two inches in diameter. The plane in which the hooks are turned is such that they are not seen when the whole is viewed as a letter U. In order to avoid cutting the hands while lifting, a piece of half-inch iron gas-tube is placed on the bend of the U, which is made square to enable this to be done, the tube having been slipped on before the wire was bent up.

When employed to lift the plates, one pair of hooks is applied to the positive lead strip, and one pair to the negative. In this way two persons can lift small or large sections with ease, and lower them gently into the cells without risk of breakage. Sections are now made in so many different ways that no general mode of lifting into the pots can be indicated, and in most cases their construction shows some method of procedure which is evidently the best; but these lifting hooks would, in the majority of instances, be found useful.

Each cell, when completed, is put back into its place upon the shelf. To effect this in the best way,



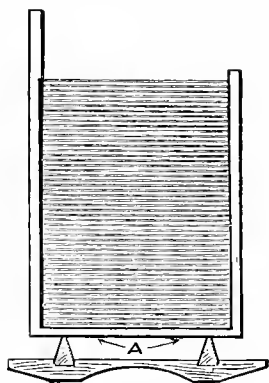


FIG. 11.—D.P. LEAD STRIP  
POSITIVE.

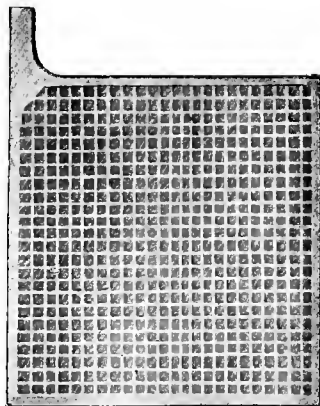
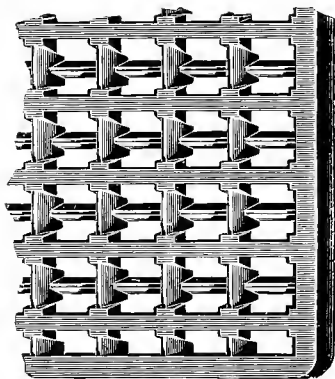


FIG. 12.—D.P. NEGATIVE PLATE.



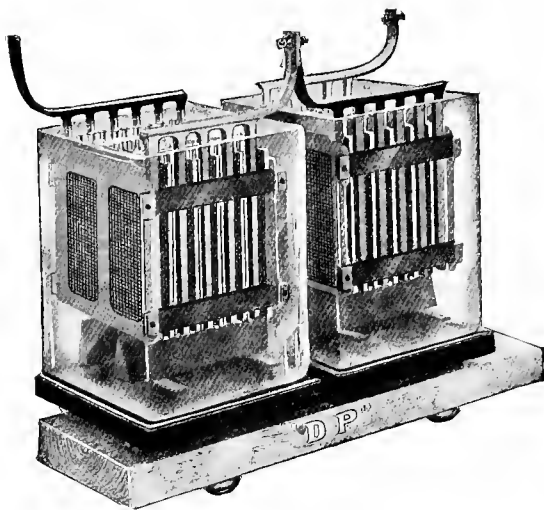


FIG. 13.—D.P. CELLS.

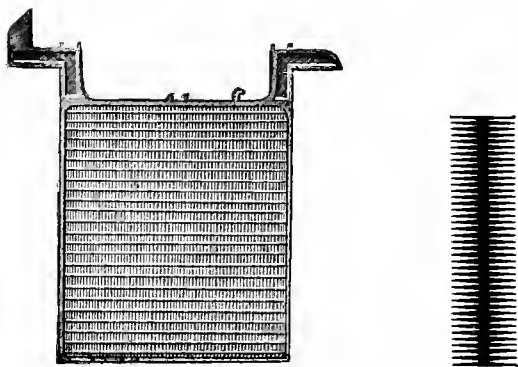


FIG. 14.—D.P. LUMFORD POSITIVE PLATE AND SECTION.



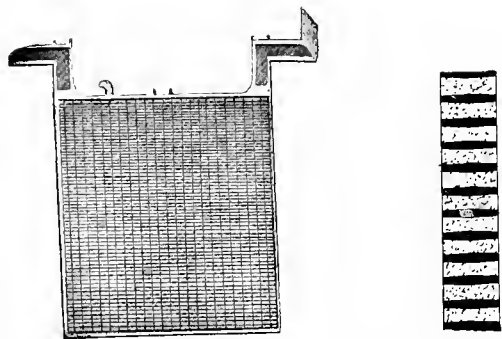


FIG. 15.—D.P. LUMFORD NEGATIVE PLATE AND SECTION.

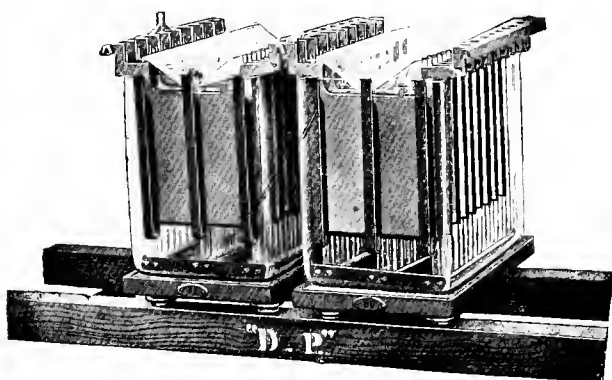


FIG. 16.—D.P. LUMFORD HEAVY TYPE CELLS.





FIG. 20.—N.S. CELL. THE PELLETS BEFORE BEING  
PLACED IN THE POROUS JAR.

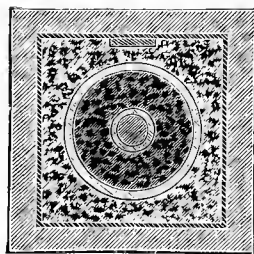


FIG. 18.—N.S. CELL.  
SECTION.

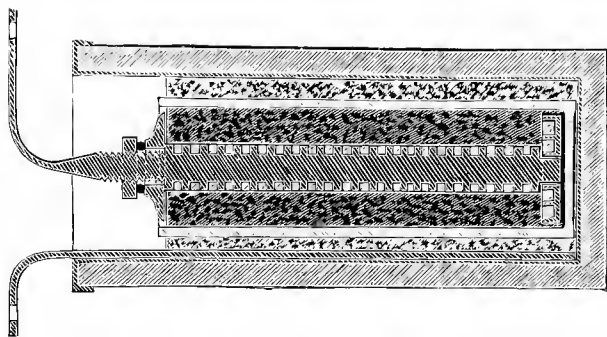


FIG. 17.—N.S. CELL.  
HORIZONTAL SECTION.





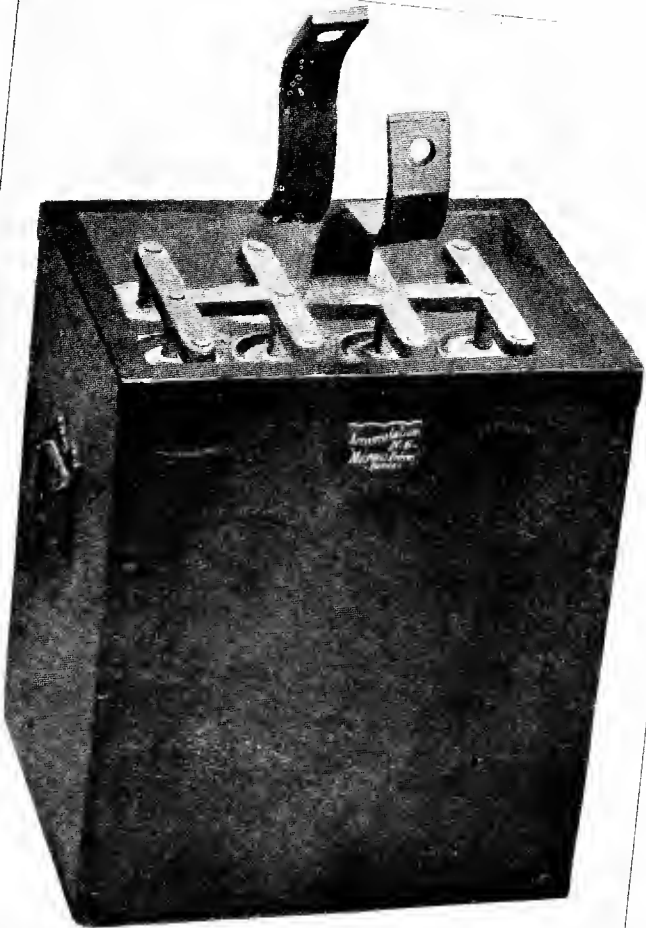


FIG. 19.—N.S. CELL. COMPLETE.



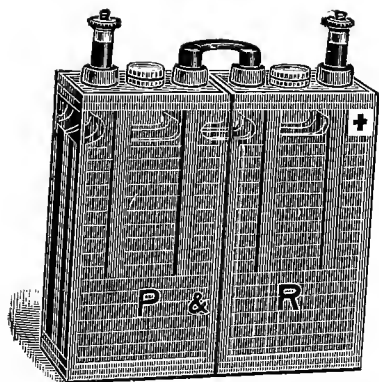


FIG. 21.—PETO & RADFORD CELLS.

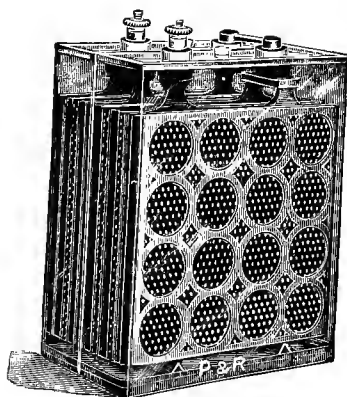


FIG. 22.—PETO-RADFORD ARMoured ACCUMULATOR.

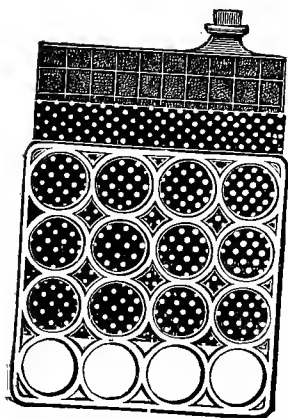


FIG. 23.—PETO-RADFORD ARMoured PLATE.

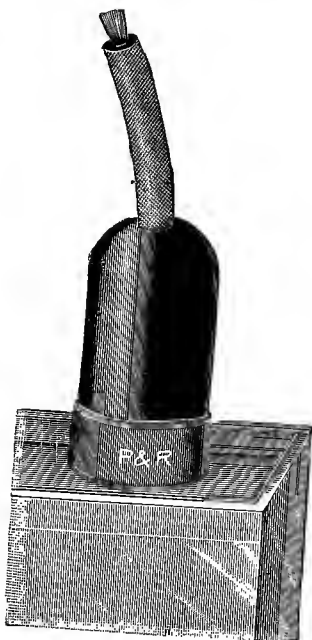


FIG. 24.—INSULATING NUT.



lift the cell now upon the floor on to its cell-board, and then lift the whole together into position upon the insulators. For high shelves, a staging (*i.e.*, tressels, with planks laid across them) is necessary, on account of the great weight to be raised.

It is always desirable that the pots be so placed that the attendant can see the edges of the plates, and consequently obtains a view between them at the same time.

When the sections are very large, and the plates heavy, it is the practice to send the plates from the factory separately and not in ready-made sections. Also the negative plates are sent out unformed, and the positive plates only partially formed.

On arrival, the plates must be carefully unpacked, then the section building is proceeded with. To effect this, a pot (glass or lead-lined box) is placed on the ground, or, better still, upon a wooden stool. The positive and negative plates are then put in in their proper order. A suitable iron mould holds all the lugs together, one for each side. With some rods of lead and an oxyhydrogen blow-pipe the moulds are filled with molten lead, resulting in the two classes of plates becoming joined together with bands of lead and connecting strips, these strips having been fixed in the iron moulds before melting all together. Thus the section is built up in the pot. Glass tubes are then inserted to act as separators. In most cases a frame of ebonite, or

glass tubes and ebonite is dropped into the bottom of the pot first, to keep the separators in place. Lastly, to hold the plates in their place, two so-called springs of lead are pushed in, one side of each pressing against the end plate and the other against the side of the pot, one spring to each edge of the end negative plate.

When all the cells are in position, they are ready for connecting. Solder, or bolts and nuts, or clamps, are used according to circumstances. Solder is often employed in conjunction with bolts and nuts, or clamps; but this is not essential if there is a good surface of the lead strip of one cell in contact with that of the next, and provided these surfaces have been well cleaned. The ends of the lead strips are turned up, so that those of two adjoining cells with the junction appear thus:  $\perp$

In some constructions the strips have to be bent horizontally, instead of vertically.

If the junctions are not in thorough contact, they will become hot when a current is flowing. It is desirable to make the connections include as little lead strip in the circuit as possible, thereby diminishing useless resistance and consequently waste. The insulators may be steeped in paraffin wax, which has the advantage of increasing their insulating properties, besides permitting the boards, on which the cells stand, to be shifted with great ease; and in practice this is found convenient for placing them

straight. The room should be cool and shady, for sunlight falling upon the cells is a constant source of breakage, which has often been attributed to some chemical action ; but the true explanation is probably to be found in the unequal expansion of different portions of the glass. Evaporation also is thus kept at a minimum.

A water tap and sink should be in every accumulator house. When possible, it is a good plan to have a space behind the shelves wide enough for a man to pass. The edges of the plates can then be viewed from each side. The distance between shelf and shelf should be such that the cells may be easily looked into from above. If the battery be erected as mentioned, the edges of the plates will always face the person inspecting them. Brass or gun-metal clamps may be kept clean by brushing them over with paraffin wax, melted in a metal or glue pot, after they have been screwed up. The waxed connectors also give indications of bad contact, by the heat, generated at such points, softening the paraffin and causing it to appear of a different colour. Vaseline is often used for the purpose. "Anti-sulphuric acid varnish," which resists the action of acid, can at present be purchased. This, as the word implies, is a varnish that is not attacked by the electrolyte. For many years the author has used such a varnish for marking positive connections red, and negative black. It is made of shellac dissolved in methylated spirit

or wood naphtha (it may be bought under the name of shellac varnish), coloured with vermilion or lamp-black ; but there is no reason why any other colouring matter should not be employed, when desirable. These special varnishes, ready for use, may be obtained from Messrs Griffiths Bros. & Co., of Macks Road, Bermondsey, London, S.E. It is sold under the name of Anti-sulphuric Enamel, and is guaranteed acid and oil resisting in its properties. This enamel is usually sold red, black, and transparent. The last-named is very useful for brushing over the connectors and cables. The two colours will be found convenient not only for painting the positive and negative strips red and black, in order to facilitate the distinction of the plates, but also in other parts of an installation for distinguishing the polarities.

The author employs this paint extensively for the connections, marking the section strips, and for coating all conductors in the accumulator-house. He cannot speak too highly of this material, and it has proved of the greatest service. This enamel also withstands heat, and it is employed at Broomhill to paint the exhaust portions of the gas engines, causing these parts to look as nice and bright as the rest of the engine ; which under usual conditions is never the case.

Clamps not made of a similar metal to that of the strips—which is almost invariably the case—frequently give trouble in consequence of the galvanic



action set up between the two different metals in the presence of moisture, resulting in the destruction either of the leaden strip or of the clamp. The author has devised a very simple means of overcoming this difficulty, viz., by placing a thin slip of zinc sheet between the lead strip and the clamp, so that there is no direct contact between the two except through the zinc; for in the case of all metals usually employed for the connecting strips, as well as the clamps, zinc is the one which is acted upon under the circumstances mentioned. Consequently, the portions likely to be injured remain intact; only the zinc crumbles away, and this, when necessary, can be replaced without inconvenience and practically at no expense.

All the difficulties encountered in lifting heavy cells in confined spaces are surmounted by erecting an overhead traveller, with dynamic pulley-blocks, on which hangs a suitable cradle, having an adjustable counterpoise. By this plan a cell may be placed upon a shelf, or removed, in a minute, no matter how heavy it may be. Such a cradle is shown in the frontispiece. The movable counterpoise enables the platform of the cradle to remain level, whether a cell is on or off it; and the point of suspension need not be over the cell, which would render its service useless where shelves exist.

The spanners employed in an accumulator-house should have wooden handles, to prevent the risk of

making a short circuit when they are employed to tighten up the connections, and this also avoids "shock" to the person.

The floor should be of vitrified blue, or yellow brick, diamond pattern and falling in all directions towards a drain. This admits of the floor being easily washed by flooding it with water, and the pattern allows it to be dry under foot at all times. Wooden floors rot very soon by acid spillings and by the spray. The room should have nothing in it which spoils by contact with sulphuric acid fumes, while good ventilation is essential for safety and for the health of the attendant. A battery in use, and even when resting, gives off hydrogen, and when this is diluted with air a highly explosive mixture results. Therefore, if proper ventilation does not exist, an explosion will probably occur should a flame of any kind be brought into the room or near it, especially on board ships. In addition to this danger, it would be almost impossible to enter the apartment during charging hours on account of the pungency of the atmosphere. There have been several serious accidents from the neglect of such a necessary precaution. The actions of breaking a connection if a current should be flowing, the lighting or extinction of a lamp in the accumulator-house, might even produce a dangerous explosion, since a spark is created under these circumstances.

Those who put up batteries suffer certain incon-

veniences, *e.g.*, sore hands and the destruction of clothing. There is, however, a cure. The boots should be painted with paraffin wax, mixed with an equal quantity of beeswax; this compound being pliable. An apron of sacking, backed with common flannel, should be worn. The clothing ought to be of woollen material, sewn with worsted, not cotton; because wool is little affected by the acid. (In fact, the acid is a good test as to whether woollen goods are adulterated with cotton.) The shirt, if made of cotton, should be dipped in a solution of strong washing soda, and then rough dried. By paying attention to these matters the clothing is fairly well protected. A bottle of ammonia fortis ought to be kept in the accumulator-house, in case of an accidental splash of acid on clothes liable to injury. The wetted stopper of the bottle applied to the stain at once neutralises the acid, and prevents a hole from being burnt in the material.

While operations are being carried on, a pail of water, rendered strongly alkaline with washing soda, should be kept close by, in which occasionally to dip the hands in order to prevent the skin from smarting under the action of the acid. In the event of a splash of acid entering the eye, the best procedure is to wash it well with warm water (failing this, with cold), then put in a drop or two of olive oil. If the oil is not handy, any engine oil is better than none at all.

The cells are now supposed to be in position and connected together. All that remains to be done is to fill the pots with liquid, attach the dynamo cables, and start charging. It is better to paint the positive strips of the sections red, and the negative strips black, than to leave them unpainted; so that it may be easy to distinguish the positives at a glance. If no mistake has been made in connecting up, the end cells of the battery have each a free strip, quite disconnected; one end being a positive and the other a negative. The positive end of the accumulator is joined to the positive cable from the dynamo, and the negative to the negative. The dynamo must be of the direct-current type and shunt wound, or special compound wound; but the former is by far the best. It is of vital importance that the reverse connections should not be made. Nothing, therefore, must be taken for granted; the dynamo wires should be tested. To determine the nature of the leads proceed thus: take a vessel of any kind—a jam-pot answers the purpose—and two pieces of sheet lead about 1 in. wide and 6 in. long. Nail these lead strips to a piece of wood, 1 in. square in section and 4 in. long, so that the lead projects beyond the wood at one end. The nails on the opposite sides, which attach the slips of lead, must not touch one another in the wood; and the latter is better shellac-varnished. By means of common clamps, such as are used for laboratory primary cells, join the projecting

ends of the lead plates one to each dynamo cable, putting an ordinary 16-c.p. lamp in the circuit, so as to prevent too much current flowing. The dynamo cables will probably be found too large for these connections. Therefore, it is more convenient to attach a piece of No. 16 or 18 S.W.G. wire to the end of each cable for connecting up with the testing cell. Place in the pot dilute sulphuric acid, of about one part acid to ten parts water. Clean the mounted pieces of lead by scraping or rubbing with sand paper; place them in the liquid, and start the dynamo. In a few minutes examine the strips of lead; one will have become brown, and the other grey. Then trace which dynamo cable is joined to the lead that has become brown. This is the positive cable, and it should have its end painted with red shellac varnish for future distinction. The test concluded and the dynamo stopped, the cable marked red is joined to the positive end of the battery by means of a suitable clamp, or by solder; and the other cable is similarly fixed to the negative end.

A very pretty little pole tester is supplied in this country by all vendors of electrical supplies. It may be put in the waistcoat pocket, and can be used without a lamp or other resistance in the circuit. (See fig. 27, which represents this apparatus, full size). The metal piece of tube can be revolved to protect the glass. It will be observed that there are two small knobs in the liquid, both of which are bright before

using. The one connected to the positive wire remains bright, whilst the other becomes purple. After a test, the normal conditions are restored, because the purple matter, which has been set free, becomes re-dissolved; a process which can be accelerated by giving a shake to the instrument, so that the latter is always ready for use.



FIG. 27.—POCKET POLE TESTER.

The solution is an iodine compound in glycerine. The author has found this little tester invaluable for attaching a variety of apparatus to an electric circuit, where it is important that the current should enter in a particular direction; also for testing leakage, to which reference is made in another volume. These pole testers can also be obtained in a modified form. The metal mountings are varied and a small tube is added, the latter being used for a spirit-level. (See fig. 28.) The instrument, therefore, can fulfil a double duty. As a large number of instruments require to be placed level, the recent addition to the tester is an advantage. Many accidents will be avoided by the use of this apparatus.

The author has found that red iodide of mercury and iodide of potassium, dissolved in glycerine, is a compound which serves well for a pole tester.

Glycerine, having a high resistance, permits of the two pieces of metal employed for the test being placed within an inch of one another for a pressure of 100 volts. To give an idea of the quantities used: to 1 oz. of glycerine add about half a teaspoonful of each of the iodine compounds; to accelerate the dissolving, place in very hot water the vessel containing the liquid and stir with a glass rod. It must be borne in mind that this compound is very

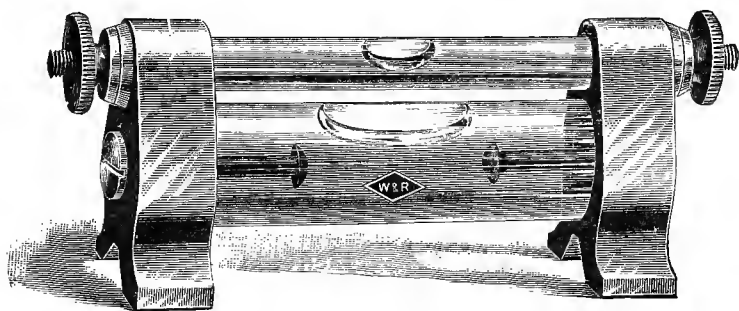


FIG. 28.—POCKET POLE TESTER, WITH SPIRIT-LEVEL COMBINED.

poisonous. Blotting-paper, damped with the liquid, may also be used as a pole tester. The ends of the two wires to be tested are placed upon the paper about an inch apart. That wire which produces discolouration will be the negative. A good solution may also be obtained by omitting the red iodide of mercury. This is mentioned because some may find a difficulty in using the mixture of the two iodides.

Since it is imperative to start charging directly the cells have been filled with the electrolyte, and to continue the process till the liquid sparkles sharply (or, as it is generally termed, "boils," or "gases"), it is better not to fill up till everything is ready. The strength of the acid solution depends upon how far the process of forming has been carried, and the better the plates are formed the greater the advantage to the customers; otherwise a long charging has to be given before any real storage commences. The general reason assigned why plates are not sent out fully formed is that the liability of the paste to fall out during transit is reduced.

Authorities differ as to what strength the solution should be. Acid too weak, or too strong, destroys the plates. If the plates are sent out unformed, which is usually the case when the plates are very large, then the acid solution employed is about s.g. 1.100. When the plates are sent out formed and discharged (they are always discharged before leaving the works), then the electrolyte should be about s.g. 1.170. In all cases the s.g. of the electrolyte rises to 1.200 or 1.210 when the plates are fully charged.

It is advisable that the electrolyte should never be denser than 1.220. Should it become so, water must be added. It may be interesting to many readers to know the percentages of concentrated sulphuric acid and of water in every 100 parts for



various specific gravities. This information is given in the following table:—

Sulphuric Acid (Per cent.).	Water (Per cent.).	Specific Gravity of Mixture.
50	50	1.398
47	53	1.370
44	56	1.342
41	59	1.315
38	62	1.289
35	65	1.264
32	68	1.239
29	71	1.215
26	74	1.190
23	77	1.167
20	80	1.144
17	83	1.121
14	86	1.098
10	90	1.068

Great care is necessary in making up the acid solution. A large vessel must be employed, by preference, of lead with burnt seams. The acid, which must be pure, should be poured into the water slowly, and cautiously, because the temperature of the liquid rises to a high point, and splashes might do serious injury, even producing blindness. The water must never be added to the acid. It is always safest to obtain the solution ready mixed.

Pour sufficient into each cell to cover the plates completely, and within half an inch of the top edge of the cell. Many people put the acid in by means of a Wilcox acid proof pump and rubber hose. For large cells this is the best method. After filling, the

s.g. of the liquid falls considerably, but on charging rises again. When an accumulator is left at rest for several weeks, the positive plates are apt to get into bad condition, and not unfrequently the negatives also. This trouble can almost be entirely remedied by doctoring the electrolyte. Any one of the following substances may be added, a small quantity to every cell:—potassium sulphate, sodium sulphate, caustic soda, or common washing soda. Oxalic acid also is now found to be of service. In the case of washing soda, the active principle is the caustic soda, which is always present in the commercial samples. The author prefers using the caustic soda or sodium sulphate, which has met with better success in his hands than have the other substances mentioned. The proportion which he uses is 1 oz. by weight of solid caustic to 5 gallons of the electrolyte; but it must be added in the form of solution, say 1 oz. of caustic to 5 oz. of water. Any substance added to the electrolyte must be poured into the cells at the conclusion of the charging and before the engine is stopped. When the sodium sulphate is employed, the crystals must be dissolved in hot water, and about one ounce by weight of crystals added to every gallon of electrolyte.

If any of the other chemicals named should be employed, about 1 oz. by weight, in the solid, to 1 gallon of electrolyte should be used.

When the addition of any of the above-named

chemicals is made, effervescence usually takes place (especially with the caustic soda); but this is of no consequence. The effervescence is due to carbonic acid being given off, the result being that a certain amount of the acid is neutralised, and the s.g. of the liquid is somewhat lowered. Therefore, the E.M.F. of each cell is slightly reduced. Occasionally it will be found necessary to add an extra cell to the accumulator in order to obtain normal pressure; but this will rarely be required. After a good charging, the accumulator can be left to itself for many months without injury to the plates; which is a great convenience to the majority of users. Caustic soda should not be touched with the hand, as it burns the skin, while to clothing it is most destructive. Any weak acid serves as a neutraliser. The caustic soda mixing with the electrolyte immediately becomes sodium sulphate. As the latter is cheap compared with the price of the former, most persons use it; and it answers quite as well. When solid sulphuric acid containing soda is employed, it is only necessary to bring this substance to the correct specific gravity by the addition of water, a "doctored" electrolyte is made at starting.

At the present day the prepared electrolyte as purchased is so much better than formerly that the "doctoring" mentioned is not often necessary.

When a battery has been in use for a considerable time it is frequently found that the upper parts of

the plates are not in good order. Under these circumstances, when caustic soda is added, the powerful chemical action, which takes place at the moment it reaches the electrolyte, where the upper parts of the plates are situated, appears to improve the plates to a greater extent than when the sodium sulphate is added; and this is the reason why the author has so often employed caustic soda in preference to the cheaper chemicals. It is desirable to charge a battery thoroughly, and to use it for a period of two or three months before doctoring the electrolyte. There are many persons who believe that the addition of any of



FIG. 29.—ACIDOMETER.

the chemicals named is productive of no advantage; on the other hand, a large number of users hold contrary views. The writer's experience is decidedly in favour of the addition. Mr. Robertson's recent researches show conclusively that the presence of sodium or potassium is a distinct advantage.

A good plan is to place an acidometer in every cell. By this means the specific gravity *i.e.* density of the liquid, in each cell can be observed, and the variations noted during the charging and at other times. In fact, there is at present no other practical and reliable method for ascertaining the condition of each cell except by the colour of the plates. The

ordinary form of an acidometer is a sealed tube containing a paper scale, weighted at one end so that it floats upright when placed in a liquid, and its general form is that shown in fig. 29. The weight is so adjusted by the makers that the upper part of the tube, with a portion of its scale, projects above the level of the liquid. If the liquid becomes denser, *i.e.*, of greater specific gravity, the acidometer rises, so that more of the tube and its scale is exposed above the liquid, and *vice versa*. Consequently, by noting



FIG. 30.—ACIDOMETER.

the position of the surface of the liquid in reference to the scale, and taking the reading, a definite idea of the s.g. can be ascertained. It may be mentioned that specific gravity (generally written s.g.) means the comparison between the weight of any substance with that of pure water at a temperature of 15 degrees C. For instance, a solid, or liquid, of a s.g. 2, means that it is twice the weight of water at that temperature.

Mr. Hicks has devised a very pretty acidometer, consisting of a tube containing four flattened glass bulbs of different colours. One or more of these bulbs rises to the top of the tube, according to the specific gravity of the electrolyte, which finds its way into the tube through numerous holes. (See fig. 30.) It will be observed that the top is turned hook

fashion, in order to hang over the edge of the cell and to prevent it from falling to the bottom. Thus when all four bulbs are at the top the s.g. is 1.200; when all are at the bottom, the s.g. is below 1.150; when one is down and three are up, the s.g. is 1.190, and so on. It is, therefore, only necessary to notice the colour of the lowermost bulb which is up, each colour representing a given specific gravity. These bulbs can be manufactured to rise at any desired specific gravity. It may be observed that, if the hooked part of this acidometer is left too long, and



FIG. 31.—PIPETTE.

fluid gets into it, there is the possibility of a small amount of liquid syphoning over. This having proved a source of trouble to some users, it is thought best to point it out, so that if the hook in any case should be found too long, it may be shortened before any harm is done, or else kept free from liquid.

A pipette is constructed on the same principle, and for a similar purpose. (See fig. 31.) Its method of employment is the following:—The rubber tube is dipped into the liquid; the rubber bulb is pressed and released, in this manner liquid is drawn up into the tube containing the coloured bulbs, and retained there by atmospheric pressure. The specific gravity

of the liquid can be observed by the position of the

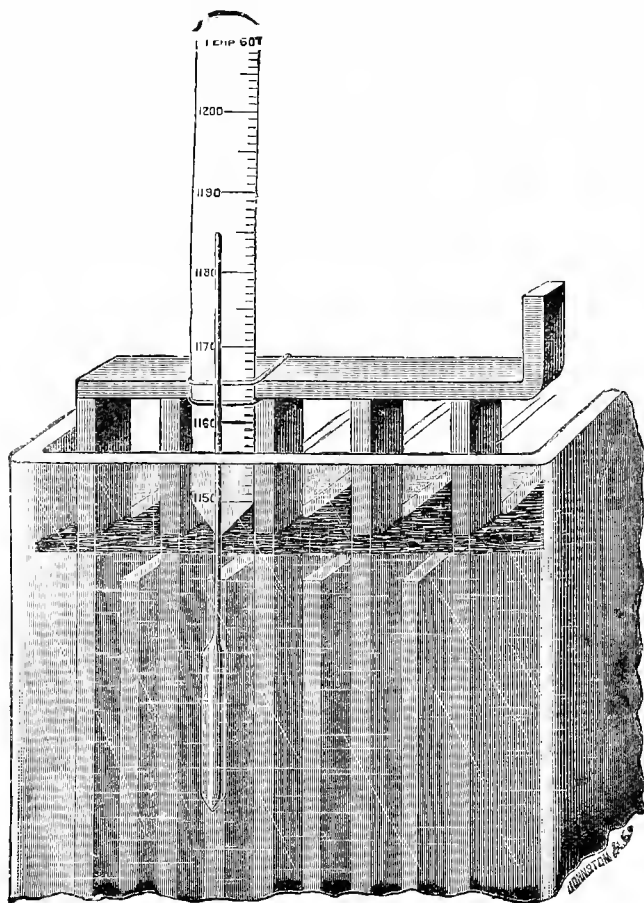


FIG. 32.—HOLDEN TYPE OF ACIDOMETER.

coloured bulbs, in the same way as with the acidometer.

The Holden type of acidometer is shown in fig. 32. The floating portion is made of ebonite suitably weighted at the lower end. The scale is attached to the connecting strip of one of the sets of plates, and indications are read from the position which the upper end of the float occupies in respect to the markings upon the scale which, as may be noticed in the plate, reads at 1.185. The best way to attach the scale is by an indiarubber band, or a piece of lead wire.

The author believes that he was the first to observe the state of the plates by means of an acidometer and to employ a modified argentometer, such as is used by photographers for ascertaining the strength of nitrate of silver solutions, long before acidometers were thought of, and at a time when absurd devices were being brought out for estimating the amount of charge existing in a cell. He was also the first to recommend the use of cover glasses and the various methods of building up sections so largely in use at the present time and the forms given to the plates. Naturally all these points would present themselves to any intelligent worker very early in the field, as the writer had the good fortune to be.

Over the top of each cell is now placed a curved glass slip, the convex face towards the liquid. These curved glasses do not, in most cases, cover the whole of the opening of the pot, because the lugs of the plates project above the cell. With some builds of sections the glasses may be laid on the tops of the



connecting strips. With others flat glasses resting on the lead bands of the sections, and touching the liquid, are employed. Any spray driven off is collected on the glass and runs back into the cell, thus assisting to keep the level of the liquid constant and the room free from acid spray.

Various other devices have been brought out from time to time to keep down the spray. Messrs. Drake & Gorham have employed pounded cork, rendered water and acid proof by being soaked in oil or some similar substance. Another device consists of covering the whole surface of the liquid with small floating blown-glass balls, each about the size of a pea. The cork is open to the objection that you cannot see the plates from above, and the glass balls are undesirable, since they continually break, and a quantity of broken glass in the pot is the result. In the early days of accumulators, petroleum or oil used to be floated on the surface of the electrolyte, which, within a short time, became muddy. Whatever the substance may be that is floated on the surface of the liquid, it must necessarily impede the use of an acidometer; and furthermore, the greater the freedom permitted for gas to escape, the better the plates are kept in order. Glass covers are, therefore, to be preferred from every point of view. In those cases where powdered cork or any other floating material is employed to keep down the spray, a clear space may be obtained for the use of an acidometer by placing

on the surface of the liquid a small ring of wood or other light substance which will float, and with a hole large enough to pass the acidometer through. It will be evident that this hole will be kept free of all impediments.

The battery is now ready to start charging, and this should be commenced without delay.

Before proceeding to the next chapter a description of the Broomhill accumulator-house will not be out of place, since it has been erected as a model. Completed now more than twenty-two years, its practical convenience has been amply tested and proved, so much so that it has been copied in other installations. A representation of the room is given in the frontispiece. The other frontispiece shows the Broomhill engine-house.

The structure is about twenty-eight feet long, by eleven feet wide, and thirteen high. The roof is flat, and in the centre there is a cast glass dome, four feet in diameter. The north end of the roof has a lean-to light five feet long, extending the whole width of the room, and facing the north. This arrangement never allows the direct sunlight to fall on the glass cells, which is frequently the cause of their breaking. In the south wall there is a large window, opening like a French casement, for ventilation; but shrubs are planted outside to keep off the sun's rays. There is ventilation also in the roof; and this is obtained by the glass dome being slightly

raised above the "lead flat," so that there is an air space all round. There are three doors at the north end, one facing east and one west, to admit air from the outside when desired; the third door on the north side enters the engine-house. The shelves run north and south, and are two feet from each wall, leaving a good space between the cells and the wall sufficient for a man to pass and to work. The two rows of shelves have three tiers in each, with a broad alley down the centre. The shelves are three inches thick and fourteen inches broad, and rest on bearers screwed and let into standards, six on each side, three inches thick, twelve inches wide, and about eight feet high. The tops are tenoned into pieces of wood, which bridge over the two-foot pathway, and are let into the wall. Bolted through each wall, running north and south, there is a piece of timber which these cross-pieces are let into and screwed; thus, there is no possibility of the shelves falling inwards or outwards. The bottoms of the standards rest on a chequered blue vitrified brick floor, laid on concrete. The shelves, being broader than the standards, have the ends mortised in such a way that, though loose on their bearers, it is not possible for them to shift when once laid in their places. The distance between them is sufficient to enable the cells to stand with seven or eight inches to spare, thus allowing an easy examination of the plates to be made from above. There are zinc

plates nailed on to the edges of the shelves, having numbers painted upon them in black on a white ground, in order that each cell may be identified. Each cell-board carries a label, stamped with figures giving the date of its erection. The floor is slightly inclined, and, being chequered, is easily washed down without remaining wet under foot; and there is a grating at one end to carry off the water. There are also a sink and a water tap in the small room adjoining, and a small place adjoining (some six feet square) for an acid tank and other requirements strictly necessary for an accumulator. The walls are cemented, the ceiling is match-boarded, and all woodwork sized and twice varnished. Two fifty candle-power lamps, let into the ceiling, light the room, the switches being on the shutting post of the entrance door. There is a large Wenham gas burner, should it ever be wanted; also a gas-soldering apparatus; and a portable lead-burning arrangement devised by Mr. Stephen Holman, of Messrs. Tangye; likewise oxyhydrogen blow pipe apparatus. A wall-connector is provided to enable a portable lamp to be used. This is most useful in an accumulator-house for the examination of the sections, whenever required. All windows and skylights are barred, to keep out intruders of a badly-disposed kind. The design of the shelf-racks is such that eight feet from the floor all is clear, even the lamps being above the ceiling line. This space allows an

overhead half-ton traveller to run north and south, the rails being laid upon timbers borne by the cross-pieces between shelf-standards and wall. There is a special cradle with adjustable counterpoise, so made that the cells may be lifted with perfect ease without requiring the point of suspension to be over a cell. The pulley blocks and traveller were made by Messrs. Tangye, and the cradle was devised at Broomhill. So successful is this lifting arrangement, that in a moment one man can move a cell filled with liquid from one given point to another, and to any level. For the sake of rapidity, it is more convenient to have two men—one to look after the cell and the other to move the traveller and work the blocks.

Each set of shelves, running north and south, with the small returned ends, holds 55 cells, each weighing about 4 cwt., 110 in all. At every third cell there is an upright standard, and between each cell a loose prop is placed betwixt shelf and shelf, to prevent any tendency of the wood to bend under the weight. The bottom shelf is three inches from the ground. At the south end the shelves are returned sufficiently for four cells on each row, and leaving a small passage through to the south window. Consequently, there is room for 114 cells, but four places at the southern end are unoccupied; hence 110 cells are installed. All cells rest on insulators, and are connected one to another by special cast-iron and gun-metal couplers, each having an attachment to take

a cable. The latter arrangement is most useful in case of need, such as for cutting out one or more cells at any time, and for experiment. Against the north, and a small portion of the east wall, there are also shelves which carry twenty-one cells, employed in connection with the counter E.M.F. governor.

The two batteries of 55 cells are, at the present time, July, 1905 (one on west and one on east side), of the D.P. Lumford heavy type.

The twenty-four counter E.M.F. cells are D.P. type built sections.

There are other cells in position for experimental and for testing purposes.

The frontispiece shows the arrangements, also the cradle to illustrate the method of using the latter.

In the Broomhill Accumulator House 110 cells can be unpacked, set up, and started charging in ten hours by six men—provided the sections are sent ready made—a result which probably exceeds the fastest work on record.

## CHAPTER III.

### CHARGING.

THE first charge differs in some respects from charging in the general way. When the sections are sent out built up and plates formed, then the following method of proceeding should be observed. The manner of dealing with plates sent out unformed will be treated later on. There should be a steady run of thirty hours without stoppage, if possible, or not less than ten hours a day during three successive days, for the size of cells commonly in use. The electrolyte will then commence to boil; it will have a milky appearance, due to the quantity of gas bubbling through the fluid, and, if the acidometer-reading be observed, it will be found that the s.g. has risen to about 1.200, or even higher.

The word "boil" is meant to indicate not a rise in temperature (although, in fact, there is a slight rise), but simply the appearance of a liquid in that state. The charging must be continued till every cell boils in an equal degree. The current should be

kept well within the permitted maximum. For some weeks, probably, there will be a difficulty in getting the cells into an equal state, and long charging alone will secure this. Over-charging does no harm whatever, unless the current is too great. If one particular cell, here or there, will not boil, it is best disconnected from the circuit during the hours of discharge, but it must be reinstated when charging is started. Should this fail to attain the desired result, the plates must be examined. Every cell must be separately tested for E.M.F., which should not be less than 2 volts; if under 1.9 volt, the cell has been discharged as low as is consistent with safety. When nearly charged, 2.1 to 2.2 volts per cell will be registered. At the conclusion of a charge, each cell, for a short period of ten to fifteen minutes, gives as much as 2.3 to 2.5 volts. Then the E.M.F. drops to near the normal, and, after a slight discharge the usual E.M.F. will average 2 volts per cell, as nearly as possible. These tests are taken on open circuit—that is, when the cells are neither charging nor discharging.

There are two convenient pieces of apparatus for ascertaining the E.M.F. of individual cells. One instrument consists of a 2-volt lamp mounted on a small rod of ebonite, which has the end tipped with a metal point, the latter being in electrical connection with one loop of the lamp. The other loop is continued to a terminal, with a piece of wire attached,



ending in a metal cap with a point on it, which serves as a protector for the lamp when out of use. It is necessary, when testing, to place the point on the ebonite rod upon one strip of the plates in the cell, and the pointed cap at the end of the wire upon the other strip. The plates are now short-circuited through the lamp, and by its brightness the condition of the cell may approximately be ascertained.

The other instrument is a more scientific one, and consists of a small voltmeter, very portable and well protected (see fig. 33), which registers from 0 to 3 volts on a very open scale, graduated to tenths, and is dead-beat. In some forms of cell-testing voltmeters the terminals have wires connected to them, having metal points at the ends. In others, there is only one such wire, the other terminal being a rod, carrying a metal point at the end. To use this apparatus it is necessary to press the points on two plates in a section of opposite polarity, and read the voltage upon the dial. If the instrument is made with a central zero, it is immaterial as to which point is in contact, say with the positive plate, since the indicating needle can read on both sides of the zero. If, however, the scale starts with zero at one end, then if no reading should result, the points pressing on the plates must be changed over. The makers of accumulators usually start with a series of plates of given sizes. They then from each size build sections containing various numbers of plates. For

instance, suppose the manufacturer makes but three sizes, small, medium and large, then he will offer sections made from each size containing, perhaps,

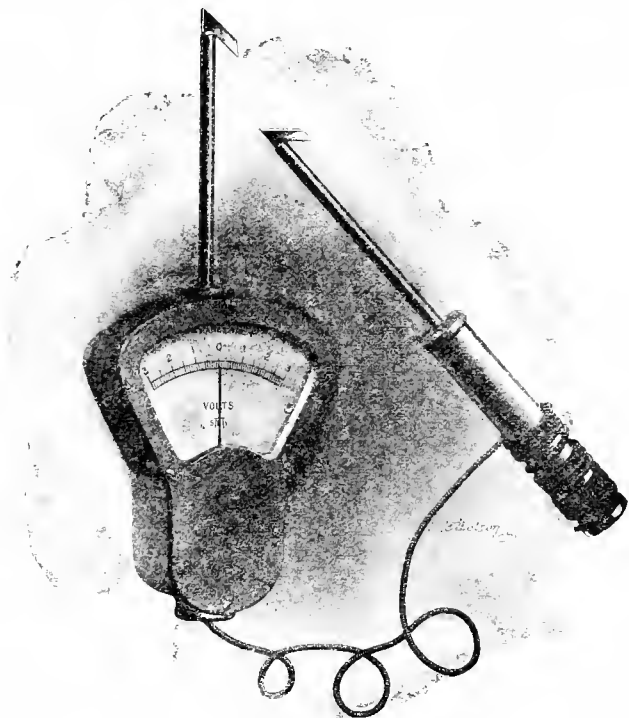


FIG. 33.—CELL-TESTING VOLTMETER.

7, 15, 23, 31, or more plates. In this manner the manufacture is simplified and cheapened, and, at the same time, any desired output of current can be given.

The remarks which now follow mostly apply to all types of lead plates, except where it is evident from the context that only the pasted grids are referred to.

For pasted plates, the proper charging rate is 6 ampères per square foot of positive plate (not surface). Thus, in a 15-plate cell, which contains 7 positives, where 20 to 22 ampères should not be exceeded for charging; then in the 23-plate size, with 11 positives, 33 ampères is the maximum charging current. If a much larger current is passed, the cells boil as if they were fully charged, showing that the surface of the plates is insufficient for the current to act upon; and the excess of current does its work by simply decomposing the water of the electrolyte, creating volumes of gas and heating the liquid. Independently of this waste, the plates are injured. These figures also apply to the discharge.

In the most recent types, the grids and paste have been so much improved that it is possible to charge without injury such a 15 and a 23-plate cell as high as 30 and 46 ampères respectively, or an increase of at least 30 per cent. on the rates mentioned; and when these sections are built up, in the most modern manner, the charging current may be still further increased, because the action over the whole surface of the plates is more equal. With recent plates, the charging and discharging current may be taken at a fraction over 8 ampères per square foot of positive plate. The object of stating the lower figures

previously given is to afford information to the users of the older types, and in cases of doubt, where the user is uncertain as to the construction. It must always be borne in mind that a very small charging current over a long period is apt to injure the plates. To put this minimum current in the form of a rule, it is advisable that the charging current should not fall below one-tenth of the maximum current.

In the section most generally employed, the positive plates are about 8 by 9 inches, the negative plates being of the same size or slightly larger; and both are approximately a quarter of an inch thick. The area of each side of every plate is, therefore, as nearly as possible half a square foot.

The E.M.F. of the charging current at starting should be, under ordinary circumstances, about 5 per cent. higher than the normal E.M.F. of the battery. If the battery has been much discharged, the difference of pressure should not exceed 2 per cent.; otherwise too large a current may flow. After a short time—which may vary from a few minutes to half an hour—the E.M.F. of the charging current may be raised to 10 or 15 per cent. above the normal E.M.F. of the battery. This state of things may continue till the charging is nearly completed, when there is a rapid rise of pressure in the battery; and it may be necessary (if it be desired to keep the charging current constant) to raise its E.M.F. 30, or even 40 per cent. above the normal pressure of the battery. For

instance, if a battery were to consist of 50 cells, its normal pressure would be 100 volts. If it be desired to keep the charging current constant, the battery being assumed to be in good order, the E.M.F. of the current at starting should have a pressure of 102 or 105 volts, according to the degree to which the battery has been discharged. In about half an hour the pressure of the charging current should be raised to 110 volts, or more, till within an hour of the end of the charge, when the pressure should be continually raised till it reaches from 130 to 140 volts.

Where no provision exists for keeping the charging current constant, it will be found that if, at starting, it is normal, then, as charging proceeds, the current grows less and less; consequently, the time required to run in such cases is very much longer than when the current can be kept constant. It is well to remember that for the first charge, as well as for subsequent charging, a battery keeps in far better condition if the charging current is kept constant. If the charging current is very small, say one-tenth of the maximum, then, however long the run, the cells do not appear to charge; unless they be in perfect order and the insulation exceedingly good, which is rare, and this proceeding, as has been already stated, is to be deprecated. So much for the practical side of the charging question as regards pasted plates and many kinds of plain lead plates when they are sent out formed.

The charging of unformed plates varies from the description given only in the fact that about 70 hours continuous charge must be given. No stop is allowable even for a few minutes till 12 hours have passed. After 70 hours, the unformed plates should have the appearance of a healthy charged battery. If not, the charging should be prolonged. Then a discharge may take place and not before.

Probably 300 or 400 hours of charging, with discharges between times, is required before the plates are properly formed, assume a good colour, and the s.g. of the electrolyte becomes stable. It often happens that the lower corners of the negatives buckle, sometimes all along the lower edges, whilst the positives usually remain straight when this occurs. When this happens, the lower edge of the next negative curves the opposite way, and so on right through the section, the struggle being to buckle so as to keep the resistance between negatives and positives equal, thus, figure 34 :

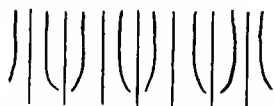


FIG. 34.—LOWER END OF PLATES.

This occurrence need produce no alarm. It results either from the section not having been put together quite square, or that the end negatives were not manufactured in the same manner on both sides. The remedy is simple, after allowing the buckling

process to go on for some time, say a month, when the plates will be softer, then with some wooden slats bend the buckled parts straight again. After going through the process once or twice the trouble will not recur.

With these large sections it is usual to make the plates of such a shape that they are supported by the edges of the pot. Consequently, care should be taken to see that the glass vessels are strong enough to support the weight, and if the plates rest on the edges of a metal lined box, then to observe that the insulating support is satisfactory, otherwise the lead box will short-circuit the plates. When lead-lined boxes are used, a specially-mounted little glow lamp is employed to examine between the plates. This tiny lamp is mounted upon a long rod (see fig. 35), in an acid-proof manner, and can be inserted between the plates right to the bottom of the section.

For cells containing any type of lead plate with dilute  $\text{H}_2\text{SO}_4$  for the electrolyte, the result of charging is to convert  $\text{PbSO}_4$  on the positive plates into  $\text{PbO}_2$ , which change is thus effected.  $\text{SO}_4$  goes to the electrolyte in exchange for O ; the liberated  $\text{H}_2$  of the water ( $\text{H}_2\text{O}$ ), joining with the  $\text{SO}_4$ , forms  $\text{H}_2\text{SO}_4$ . The next action is, another atom of O joins the  $\text{PbO}$ , making  $\text{PbO}_2$  ; and the liberated  $\text{H}_2$  of the  $\text{H}_2\text{O}$ , going to the  $\text{PbO}$  of the negative plate, forms  $\text{Pb}$  plus  $\text{H}_2\text{O}$ . The first and final chemical composition of plates and of the electrolyte is known,

but the chemical equation or equations, showing the

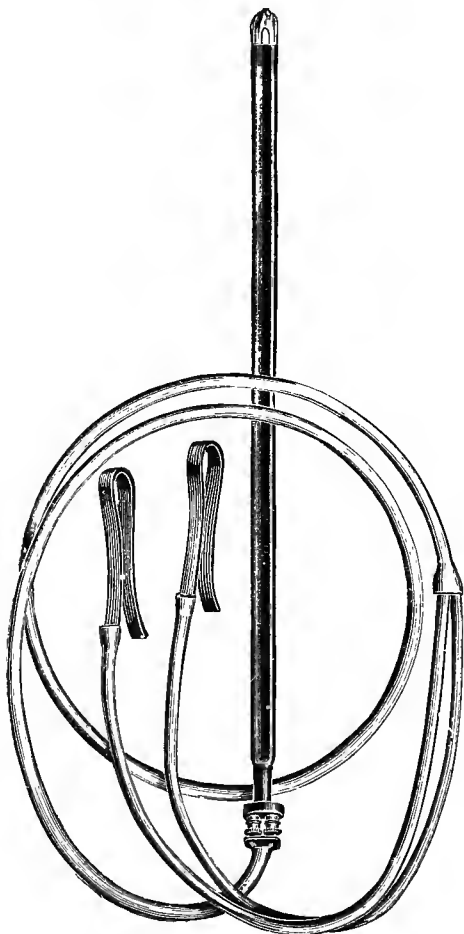


FIG. 35.—CELL-INSPECTION LAMP.

change from the first to the final state, though given



in many ways by able hands, may still be regarded as problematical. No attempt will therefore, be made to give equations which might lead to error. The following three expressions convey a general idea of what takes place:—

POSITIVE.	ELECTROLYTE.	NEGATIVE.
1st stage $\text{PbSO}_4$	$\text{H}_2\text{SO}_4 + \text{H}_2\text{O}$	$\text{PbO}$
2nd „ $\text{PbO}$	$\text{H}_2\text{SO}_4 + \text{H}_2\text{O}$	$\text{PbO}$
3rd „ $\text{PbO}_2$	$\text{H}_2\text{SO}_4 + \text{H}_2\text{O}$	$\text{Pb}$

The first stage indicates the discharged cell. The second stage shows what might be termed the rational change which takes place, though in all probability a number of equations would be necessary to express what really happens between first and last states. In the second stage molecules of water have been removed from the electrolyte and an equal number of molecules of  $\text{H}_2\text{SO}_4$  added, thus increasing the strength of the acid solution. The s.g. of the electrolyte may decrease slightly in stage 3. Hence we see why the s.g. of the electrolyte increases as the charging advances. It will also be noticed that the  $\text{H}_2\text{SO}_4$  originally put in appears to play no part whatever beyond making the water a good conductor; yet, if no  $\text{H}_2\text{SO}_4$  has been added in the first instance, the chemical actions are not quite the same, and the plates are soon injured by secondary reactions, giving at the same time a lower E.M.F. Water is a very bad conductor, and therefore this liquid could not possibly be employed by itself under

any circumstances, since the internal resistance of the cell would be so high that but little energy could be obtained in the outside circuit. There is, however, an additional chemical action during charging, for gas is given off at all periods of the charge, first from the positives only, and later from the negatives. This tends to prove that water is being decomposed, the O of which does not unite with the paste of the positives, and that H is absorbed in the negatives, or goes into chemical combination with them for a time or forms some new substance in the electrolyte; but when the end of the charging approaches, and the negative can take up no more gas, H is given off from these plates. This result is evidently a waste of energy.

There is far greater loss with storage than is generally supposed, notwithstanding that many eminent men have shown great efficiency in laboratory tests. For practical purposes such tests are worthless, and no one is recommended to expect more than 65 to 70 per cent. of efficiency in the long run. These are approximately the figures obtained from eight accumulators over extended periods, as well as from a large number of isolated cells. There is no doubt that, under exceptional conditions, the efficiency may apparently be raised another 10 per cent.; but to produce this so much care and attention are requisite that in practice it is better to consider practical results than economy only to be

obtained at the cost of much labour, which means expenditure.

In getting current through the battery in the first instance there must be a loss of about 15 per cent., viz., the average difference between the E.M.F. of the charging current and the E.M.F. of the accumulator. Power also is required to get it out, if such an expression may be allowed. There is loss from leakage due to local action, to cells being in bad order at times, and many other causes which do not exist in the usual laboratory tests. The loss may be regarded entirely as "pressure loss," for to all intents and purposes the number of ampère hours put into a battery can be got out of it.

A very interesting, as well as memorable, paper on the subject of secondary batteries was read before the Society of Arts in 1891 by Mr. Robertson, and it is well worth perusal. (See *The Electrical Engineer*, December 4th, 1891.) If the most important part of the paper—that dealing with chemical questions—is correct, as it certainly would appear to be, many enigmas are explained by the writer: such, for instance, as the cause of bad sulphating; why the addition of sodium and potassium is beneficial; why the E.M.F. near the end of the charge rises so rapidly; and why, when a cell is almost discharged, its E.M.F. drops from nearly normal to zero without gradual fall. Mr. Robertson also proves how very complex the chemical

equations must be in order to express what takes place in a secondary cell.

The following is a *résumé* of the chemical portion of the paper :—

Bertholet discovered persulphuric acid,  $\text{H}_2\text{S}_2\text{O}_8$ , in the year 1878. He showed that it is the primary product of the electrolysis of sulphuric acid solutions, and that hydrogen dioxide is really due to the action of this body on the acid. The products of electrolysis vary with the strength of the acid. If the density is 1.300, practically no hydrogen dioxide is formed, while below and above that strength it is found to be present in varying proportions. High current density, under electro-negative condition of the electrodes, favours the formation. Persulphuric acid is an unstable body and decomposes as soon as the current, which has given rise to it, is stopped, hydrogen dioxide being formed during its decomposition, unless the sulphuric acid is too dilute. Hydrogen dioxide also is unstable when concentrated, but a weak sulphuric acid solution of it is comparatively stable, and the less hydrogen dioxide it contains the more stable it is; consequently, this substance is found in small quantities long after the persulphuric acid, which gave rise to it has disappeared. Subsequent workers have on most points confirmed Bertholet's conclusions. During the time that the cells are charged, persulphuric acid is present, and during discharge, the hydrogen dioxide gradually

increases ; while in a cell which has been at rest for some time, practically hydrogen dioxide alone is to be found. Experiments showed that, although persulphuric acid itself does not reduce peroxide of lead, hydrogen dioxide does so ; and this explains why cells when resting become discharged. In an ordinary cell of the size generally in use, there is usually sufficient hydrogen dioxide to undo the work of from one to two hours' charging if the cells are left to rest, and sulphating may result ; but clearly when the battery is in use no harm occurs, since the peroxides have been continually broken up with each reversal of the current. It was found that the addition of sodium sulphate to the electrolyte had but little effect, unless it was added during the time charging was proceeding ; and it was noted that where this chemical was introduced the amount of persulphuric acid was increased. Consequently, a larger proportion of hydrogen dioxide will be found subsequently than in a cell where the addition had not been made. This result might have been anticipated, since the persulphuric acid is not injurious to the plates with the larger quantity to be found under the conditions just named ; the cells might rest for a longer period without harm, although a time must arrive when, in consequence, there will be excess of the hydrogen dioxide and the sulphating will proceed as rapidly, or more rapidly, than in a cell to which the sodium sulphate has not been added. There is

strong evidence to show that certainly many months must elapse before all the persulphuric acid is decomposed.

Experiments, made to ascertain what would be the action of the presence of hydrogen dioxide in the electrolyte by adding a small quantity of this substance to the liquid, prove conclusively that the E.M.F. was much lower, or even became reversed. But the addition of the hydrogen dioxide to the peroxide paste increases the E.M.F. It would thus appear that towards the end of the charge the hydrogen dioxide is formed at the positive plate, and towards the end of the discharge hydrogen dioxide becomes diffused through the acid and finally is present on the negative plate. Lastly, the rise of E.M.F., which is usually found to exist when a discharged cell is permitted to rest for a time, may be due to a decomposition of the hydrogen dioxide having taken place on the negative plates. Mr. Robertson concludes that the majority of the troubles, which pursue the users of batteries are, owing rather to the mode of using than to faulty manufacture; which conclusion the author arrived at many years ago. There can be no doubt that the improvements in future will take the form of a modified electrolyte, which, according to Mr. Robertson's investigation, must be of such a nature as to prevent the formation of, or at once to break up, any deleterious substance which may be formed during the charge or discharge

of the battery. It is satisfactory to find that the writer of the paper referred to confirms the principle now so universal in practice, which is that in cells containing acid having a specific gravity of less than 1.200, one per cent. of sodium sulphate, or of some equivalent substance, proves beneficial, especially when the cells are at times left to rest. On the other hand, he shows that when the acid density is greater, there is less need for doctoring, because the circumstances are more favourable to the stability of the persulphuric acid; in which case the addition of sodium sulphate might be prejudicial. But it must be remembered that in practice, for the good of the plates, the electrolyte is rarely, if ever, allowed to rise much above s.g. 1.200. Therefore, it may be concluded that the addition of sodium sulphate is always advantageous.

Mr. Robertson has also made an examination to ascertain the cause of the electrolyte discoloring to a purple, which it frequently does. His tests, which were confirmed by spectrum analysis, indicate the presence of potassium permanganate. Of course, in some cases discoloration may be due to other substances depending very much upon the nature of the lead ore from which the plates were made.

If the strength of the acid solution is above 1.700, bad sulphating rapidly ensues, with great loss of capacity, although giving a good E.M.F.

The level of the liquid in the cells must be kept

constant. To effect this, the first few additions of fluid should be  $\text{H}_2\text{SO}_4$  s.g. 1.150 or 1.170; after this only water, unless it is found on completion of the charge that the acid is below the normal strength, in which case fill a few times when necessary with acid solution, as already mentioned.

Two phenomena, which have frequently puzzled the users of cells, are worthy of mention. One is that when a new battery is erected, on its receiving a considerable charge, the s.g. of the electrolyte is found to have risen, as is usually the case. This increase of the s.g. after standing a few days, or even hours, frequently also whilst the charging is in progress, is partly or wholly lost, a state of things which may continue for many chargings. When this does occur, it is a proof that the plates have not been very fully formed, and chemical action goes on within the plates while the battery is standing or charging. The second phenomenon is that at all times when charging is first started, there is a slight fall in the density of the liquid, which is soon recovered. This is due to some peculiar chemical action set up at the commencement of the charging. It is assumed in the first case that no discharge has been taken, and in both that the plates are in good order. No disadvantages attach to these phenomena.

From careful chemical analysis, made by Mr. G. H. Robertson, it would appear that only one half of the  $\text{PbSO}_4$  is converted into  $\text{PbO}_2$  in a fully charged



plate. For this there may be two reasons: (1) that there is some mechanical cause why the whole of the lead sulphate is not converted into dioxide; and (2) that the negative plates have run down and become neutral for further work upon the positives. From recent investigations both reasons would appear to apply, for, if the particles of paste of a discharged positive plate be examined, they will be found to consist of granules of  $\text{PbSO}_4$  and to contain nuclei of  $\text{PbO}_2$ ; thus showing that these nuclei have become isolated from the electrolyte, and therefore lost for practical purposes. Also the discharged paste occupies a larger space than when charged. This in itself may tend to render portions of the plate waterproof, by blocking up all the interstices. It is likewise found that the negatives exhaust themselves sooner than the positives, which may be easily demonstrated by taking the positives from a cell that is exhausted and putting them into another containing a set of charged negatives. It will then be found that a very considerable further discharge may be obtained from the plates. But in no case does it appear possible to reduce the whole of the lead sulphate to lead dioxide. In making the experiment just mentioned, it is advisable that the positives under test should be put into the cell containing the negatives, and not *vice versa*, because a chemical change takes place in the negatives when exposed to the air. In practice, it is usual to put in the positive

plates a considerably larger quantity of  $\text{PbSO}_4$  than theory would demand. The object aimed at is that only a small proportion of the paste should be converted into lead dioxide, the advantage being that the paste is stronger and less liable to fall away from the grid. It is thus evident that the paste holds in the positives better in the discharged state than when charged, and for this reason makers require their customers to finish forming the plates upon arrival at their destination. When a positive plate is discharged till the paste contains about 30 per cent. of  $\text{PbO}_2$ , it is found there is very little E.M.F. Chemical action starts from the grid to the paste. It is, therefore, important that there should be an intimate connection between the two. Many difficulties with the negative plates have been owing to this cause, as their paste shrinks away from the grid. An improvement has recently been made in the shape of the grid, whereby the shrinkage assists in forming a better connection instead of separating. Some attribute this shrinkage to the litharge being impure and containing sulphate. Many consider that, when it contains traces of sulphate, there is less chance of these plates blistering. Evidence is insufficient at present to form a definite opinion. Many makers of pasted plates prepare the grids in the Planté fashion, to secure a better contact between the paste and the grid. It is the present practice to dry the plates before they are formed in order to secure

harder paste, though this process will require longer time. The positive plates require about eighteen hours to form, and the negatives about six times as long. It is usual, therefore, to form the positives and negatives separately; but the time required is longer if the operation is not continuous.

To account for the variations of the E.M.F. in a cell, an interesting paper written by the late Dr. Gladstone and Mr. Walter Hibbert, was read at the Institution of Electrical Engineers on May, 12, 1892. In this paper an attempt is made to show that the cause is due to the formation of layers of different densities in the electrolyte, and certainly the writers go very far to prove their case. It is probable that the explanations given by Mr. Robertson, as well as by Dr. Gladstone and Mr. Hibbert, are all more or less correct; and the chemical actions as explained by them may both contribute to the result. The following is a quotation from the paper last referred to, which in part indicates the methods employed by the writers in arriving at their conclusions. The table is also a useful one for reference.

“The following figures, calculated from Kohlrausch’s results, will give an idea of the variation:—

#### RESISTANCE OF SULPHURIC ACID SOLUTIONS.

% $\text{HO}_2\text{S}_4$	Relative Resistance.	% $\text{HO}_2\text{S}_4$	Relative Resistance.
2.5	6.73	50.0	1.35
15.0	1.33	71.0	3.79
30.0	1.00	95.0	7.29

“Hence we should expect that, if the acid against the working surfaces of the plates is being concentrated during charge, or greatly weakened during discharge, there would be a marked increase in resistance.”

The tables on p. 113 are copied from an able paper, read before the Society of Telegraph Engineers and Electricians, on March 10th, 1887, by the late Mr. Desmond Fitz-Gerald, and they are given here, as they may prove of interest.

Mr. Fitz-Gerald doubts the accuracy of Mr. Howard's results, which he thinks are due either to error or to the methods employed.

This well-known experimenter has recently made, in plates to be employed in secondary batteries, great improvements which largely increase their storage capacity. The improvements consist in treating the plates with magnesium sulphate, and in the method of constructing the plates themselves, by consolidation; the result being that the active material on their surface can be increased indefinitely without incurring any loss of its conducting qualities. Mr. Fitz-Gerald described to the author an experiment, made by him, which indicates the result of  $\text{MgSO}_4$  (magnesium sulphate) treatment.

### *Experiment.*

“Two couples (A and B) formed of lead plates with immersed surface 3 in. by 2 in.; A in dilute

TABLE I.  
STORAGE CAPACITY OF VARIOUS SECONDARY CELLS.

Name of Cell.	Per lb. of Pb.		Per kilo of Pb.		Authority.
	Foot lbs.	Watt hours.	Killigram metres.	Watt hours.	
Planté,	12,000	4.52	3,664	10	Howard (?) Hospitalier.
Faure,	18,000	6.78	5,485	15	
E.P.S. L plates,	48,000	18.09	14,600	39.8	
„ R „	36,080	13.6	11,010	—	
„ S nominal, 22 lb. cell,	31,800	12	9,540	26	Fitz-Gerald
Elwell-Parker, (Old form),	6,633	2.5	22,018	5.5	Prospectus
Lithanode Battery, (Old form),	39,798	15	121,110	33	Fitz-Gerald
Lithanode Battery, “Union” cell,	47,170	17.8	14,671	39.16	G. Forbes

TABLE II.  
WEIGHT PER HORSE-POWER HOUR CAPACITY OF  
VARIOUS SECONDARY BATTERIES.

Name of Battery.	Elements only.		Cell complete.		Authority.
	Lbs.	Kilos.	Lbs.	Kilos.	
Planté,	—	—	396	180	Reynier
Faure,	—	—	88	40	Faure.
	—	—	165	75	Sir W. Thomson
„ (old model),	—	—	198	90	Reynier
„ (new model),	—	—	134	61	
E.P.S. L plates, -	—	—	133	60.4	Prospectus
	—	—	110	50	Reckenzaum
„ S „	66	30	135	61.3	Fitz-Gerald
Reynier, { Zinc positive, { Planté form,	50.6	23	117.5	53.4	Tamine
	105	47.6	—	—	Idem
Lithanode battery, (Old form), -	42	19.1	76	34.5	Fitz-Gerald
Lithanode battery, “Union” cell,	42	19	70	31.5	G. Forbes

sulphuric acid of s.g. 1.17; B in half-saturated solution of  $\text{MgSO}_4$ .

“Couples charged for two hours, with reversals when gasing freely.

“B plates removed from  $\text{MgSO}_4$  electrolyte and immersed in dilute  $\text{H}_2\text{SO}_2$  (s.g. 1.17).

“Circuted consecutively on an electric bell (wire resistance 11.5 ohms). The following results were obtained:—

“A rang bell for 3.2 minutes.

“B        „        „        19.5        „

“The difference being enormously greater in favour of B.”

The experimenter remarks that by this treatment every pound weight of the battery has a storage capacity of 1.66 ampère hours, and a discharge of 10 ampères.

Mr. Fitz-Gerald, in the course of the discussion upon Professor Ayrton's paper on Secondary Cells, before the Institution of Electrical Engineers, gave some interesting information; and as his words cannot be improved, they are retained, as far as possible, in the following abstract:—

“There would appear to be no particular reason why the metal lead should invariably be adhered to as the support for the spongy lead (which may be paste); and in many cases copper would seem to be decidedly superior to lead as a support for the active

material in the negative plate. Local action, which would destroy the copper, may be all but entirely obviated by adding to the electrolyte almost any alkaline or soluble earthy sulphate. There is a general belief that the addition of washing soda to the electrolyte is beneficial. If true, this advantage is probably due to the fact that almost any soluble sulphate can form a double salt with sulphate of lead, which salt is more or less soluble. Sulphate of magnesia particularly exerts an extraordinary effect upon the electrolyte by reason of its solvent action on the sulphate of lead. If, for instance, you take dilute sulphuric acid and a half-saturated solution of sulphate of magnesia as the respective electrolytes of two couples, in which the electrodes are plates of lead, you will find, if you pass a current through these electrolytes until the elements of both the couples freely evolve gas, that, after a few reversals of the charging current, the plates immersed in the sulphate of magnesia will give a discharge, or will possess a capacity, some 30 to 40 times greater than the discharge from the plates immersed in the dilute sulphuric acid."

Mr. Fitz-Gerald calls the litharge, or the plain lead, plate the positive; but the author keeps to the usual practice, as adopted by the manufacturers, in order to avoid confusion.

It is well to point out that the storage capacity

per pound of lead has been greatly increased by more modern methods of manufacture.

The more complex salts of lead electrolyse more easily than the simple salt  $\text{PbSO}_4$ . The question naturally arises: Why is it so troublesome to charge a battery which has been much exhausted, in which state it is almost certain that the positive plates have upon them many of the higher sulphates of lead? The probable explanation is that, lead sulphate being a bad conductor, the current cannot do its work effectually. This fact may account for the existence, in a positive plate, of far more paste than is actually required to serve a useful purpose, since, if the whole of the paste, which can be reached by the electrolyte, were to be converted into sulphate upon discharge, it might be found absolutely impossible to convert the sulphate back into dioxide.

Professor Crookes has pointed out that  $\text{H}_2\text{SO}_4$  has strong tendencies to form double salts, and that sulphates have great affinities for one another.

We have seen that as charging proceeds the s.g. of the acid becomes denser and the E.M.F. rises. Let us now examine this question. Water is a very bad conductor, and dilute  $\text{H}_2\text{SO}_4$  a good one; therefore, the weaker the acid, the worse the conducting qualities. If the dilute acid is strengthened by adding  $\text{H}_2\text{SO}_4$  until it becomes very much concentrated, the conducting properties diminish; but this stage is never reached in accumulator work. Kohl-



rausch gives the following table for the specific conductivities of an electrolyte made with water and sulphuric acid :—

s.g. at 18°C.	Conductivity at 18°C.		Per cent. in sol : $\text{H}_2\text{SO}_4$
1.1036		5084	15
1.1414	↓	6108	20
1.1807		6710	25

The arrowheads show direction of increasing conductivity.

It will be observed that, since the solution is put into the cells at s.gs. varying from 1.150 to 1.170, the mixture is approximately a 20-per cent. solution, or one part concentrated  $\text{H}_2\text{SO}_4$  to four parts water (in practice, one part to five); and again, since the s.g. at the end of a charge rises to 1.200 or higher, the solution is about one of 25 per cent., and its conductivity is about 10 per cent. better.

A well-charged cell is found to have about half the resistance of a discharged one. This is due partly to the difference in the conductivity of the electrolyte, as explained, and partly to the surface of the plates being in a better conducting state when charged.

In the discharged plate the active surface is greatly diminished, owing to the presence of the large quantity of lead sulphate, which is a poor conductor, and consequently troublesome to reduce. It might, therefore be inferred that an exhausted battery is more difficult to charge at the start than at later stages of the process; and this, in practice, is the case.

By active surface is meant that surface upon which the current can do useful work.

Certain advantages exist from the fact that the resistance of the cells becomes less as charging proceeds. Were this not the case, with a dynamo giving constant E.M.F. for all currents within its capacity, it is evident that the charging current would rapidly diminish as the charge approaches the end, in consequence of the rise of the E.M.F. of the battery. It does diminish, but not in any great degree, if a shunt dynamo is used, although the counter E.M.F. (in this case, the battery pressure) may have risen as much as 20 to 25 per cent.

The charging instructions sent out by makers frequently contain an impossible condition. It is stated at end of charge, and while still charging, each cell should give a certain E.M.F., say, for instance, 2.7 volts. In many cases this cannot be done, and the observer concludes something is wrong. The fact is the highest E.M.F. per cell can never exceed the highest E.M.F. the dynamo in use can give divided by the number of cells. But in reality it is less, owing to waste in leads, connections, switchboards, etc. For instance, if the dynamo can give 140 volts, and the battery contains 55 cells, and the losses equal, say 3 volts, then each cell cannot register more than  $\frac{137}{55}$  volts, or about 2.5 volts. Consequently if instructions state at end of charge 2.7 volts should be indicated, such a reading cannot be

obtained, and the completion of the charge must be judged by the other indications described.

With a new battery, it is a common occurrence that the electrolyte becomes plum coloured after the first or second charges in many of the cells, sometimes in all the cells. This is due to impurities existing in the positive plates which become dissolved in the liquid; probably permanganate of potash. The colour will persist until the plates are well formed, when the electrolyte will become transparent again. No harm of any kind results from the existence of this foreign matter. And the final clearing of the solution is a good indication that the plates have been formed.

The necessity for keeping all the connecting strips short and of low resistance, the junctions clean, and the cables short and large, may be illustrated by an example. Suppose a set of fifty cells, with a normal charging current of thirty ampères, which has an E.M.F. of 110 volts. Since the fifty cells themselves give 100 volts, this acts as counter E.M.F., *i.e.*, in opposition to the charging current; thus 10 volts is the true pressure which forces the thirty ampères through the accumulator, so that the total resistance for cells, cables, and connections is about one-third ohm. This is considerably increased if the connections are not clean, or the cells not placed close together to shorten the lead connecting strips as much as possible, and the cables large. It will also be

observed that if the charging current were raised to, say 112 volts a much larger current would flow, since the forcing power would be twenty per cent. greater. It is evident also that the rise of E.M.F. in the cells, as charging advances, must materially reduce the effective margin of pressure, notwithstanding the lower resistance of the cell. The methods of regulating charging currents is dealt with in Volume III. of *Electric Light Installations*, written by the author.

The next point to consider is why boiling occurs. It must be clear that, as the surface of the positive plates becomes converted into lead peroxide, the material to be acted upon by the current grows less and less, and the plates become virtually smaller; consequently, the current becomes too large for the work demanded of it upon the plates, which results in the decomposition of the water of the electrolyte, and often warming it considerably.

However, in practice it would not pay to gradually reduce the current as the charge advances. Yet it can be experimentally shown that, by reducing the current in exact proportion to the diminishing active surface of the plate, boiling never occurs, and hundreds of ampère hours may actually be added beyond what is accomplished in the usual way. Theoretically, an infinite charge in point of time, but finite in quantity, might be given if the current is continually reduced to suit the lessening active surface

of the positive, since the total quantity becomes the sum of a special form of an infinite series.

Boiling does no harm unless the paste is loose, when much material will be removed by the agitation of the liquid.

Frequent and prolonged over-charging, with currents about 30 per cent. below maximum, is the only way to reduce badly sulphated plates, which are frequently found when the cells are allowed to run too low or to stand too long. When the positive plates are in a bad condition (generally due to the battery having been over-worked, *i.e.*, greatly exhausted, or owing to short circuits within the cell itself, which evidently produces a similar result, or to leakage), it is no easy matter to get them right again, since the conducting property of the paste has become very low. Under these circumstances, complex sulphates soon form and rapidly spread over the plates almost like a growth of mould. By patient and slow charging, this grey or white sulphate, from want of adherence to the healthy oxide forming below, soon falls off in the shape of scale or powder to the bottom of the pot; and care should be taken that no portion sticks between the plates.

It must be borne in mind that the addition of caustic soda, or of the other materials mentioned, in a great measure prevents the formation of this white sulphate.

If, when the cells boil, the charging is stopped for

half an hour or more, and is re-started, it will be found that boiling does not commence for some time ; and this process may be repeated again and again. When boiling takes place a kind of gas battery is produced, both positive and negative plates being covered with a layer of gas. When charging is stopped, this gas escapes or becomes partly absorbed, so that the plates are once more exposed for a short time to the current, before the phenomenon recurs.

If too large a charging current is used for the area of the plates, buckling is likely to ensue, and very rapidly if the positives are in a bad state. Then, short-circuiting, due to plates touching one another in the liquid, soon takes place together with a great loss of paste. Buckling is due to unequal expansion of the plates, and even under the best treatment this trouble arises if the makers have not given them a proper form. Also the end negatives should be similar in texture and formation on both sides, a matter often neglected. When this fault is present there is a risk of any plate in the section buckling at the first charge. This evil can be rectified by straightening the plates by means of slips of wood. After a short time the exposed ends of the negatives become formed and as spongy as on the opposite side, then matters proceed smoothly. The paste expands on discharge, and *vice versâ* ; therefore it is absolutely necessary that such expansion and contraction should be symmetrical over the whole surface. These con-

tinual changes in the volume of the paste, after a time, loosen it from the grids; but, if these are uninjured, repasting can be resorted to. With judicious treatment, some years may elapse before this becomes necessary, and it is applicable chiefly to the positive plates.

It has been previously pointed out that the chemical action of the current on different parts of a plate is unequal, because the resistance between the places, where the current enters or leaves the plate, and the various portions of the plate is unequal. Indeed, practically, although this condition of things can be much improved, it is hardly likely that perfection can ever be attained in this respect. From these considerations it might appear that buckling must inevitably ensue, and the only reason why it does not is that, the charging and discharging current being kept low, there is no great tendency for the current to travel from plate to plate otherwise than over its whole surface. But clearly, if the current put in or taken out is too large, there would be a tendency to set up a more rapid chemical action on those portions of the plate nearest to the point or points where the current enters or leaves them. Hitherto the equalizing of the chemical action all over the plates has received the attention of manufacturers more with a view to obtaining a heavy discharge than from any other reason. It might be concluded from the foregoing remarks that,

independently of many advantages which may accrue, by equalizing the chemical action over the plate surface durability to the battery would be given.

The difficulties which may arise with the negatives will be commented on later. Buckling may also spring from other causes to be considered in the next chapter.

It might be supposed from what has just been said that when boiling (due to the current at this time being too great for the active area of the plates) commences, the risk of buckling the positives may occur. However, this is not so, because the case is not the same as when the surface of the plates is actually smaller; there is still a large surface upon which the current can do its work, but, instead of forming  $\text{PbO}_2$ , it decomposes the water of the electrolyte.

It is often necessary to give prolonged charges in order to remove any white sulphate that may form. In this event the current should be reduced, say to two-thirds or half the maximum; otherwise much paste may be removed. It must be well understood that overcharging improves the plates at all times, and *never* injures them, unless the paste be loose when the agitation of the liquid may remove a good deal of it, if the overcharging is continued for a long period.

From time to time, water must be added to the cells so as to keep the plates well covered. It has



already been explained that, for the first few times, acid solution s.g. 1.150 should be employed to keep up the level; but if the s.g. or the electrolyte should fall below the normal, then the acid solution must again be used until the normal is once more reached. It is, therefore, most desirable to place an acidometer in every cell, in order not only to indicate the s.g. of the liquid, but that, by its rise and fall, a fair estimate of the state of the plates (*i.e.* storage) may be arrived at. For instance, if the acidometer in a cell refuses to rise, then a careful examination must be made, as something is at fault; most probably two plates are touching, or one or more pieces of paste sticking between them. Again, if the apparatus rises slower, during charging, in one cell than in others, or if it should fall more in it than in any others at other times, then a leakage is taking place in that cell, probably due to one of the causes just mentioned.

When the accumulator has been in use for a long time and the plates have become very well formed, the s.g. of the electrolyte does not rise so much as it was accustomed to do in previous stages, and the nature of the boiling appears somewhat different. The gases then given off, although considerable, do not produce such a milky appearance of the liquid as formerly. The chief reason why the electrolyte does not gas so much is that the plates are better formed, and therefore a larger charging current would be

required to make the liquid boil as white as when the battery was first erected. But, if this current were to be increased, the original effects would be reproduced, although that course is not advisable.

Positive plates do not assume their healthy colour till after several chargings, as the white sulphate (some persons call the colour brick-red) sticks very obstinately to the plates when they have been allowed to dry; but before long, especially after a few discharges have been taken, it will be observed that the white sulphate falls off as a white powder or in small scales.

It is of the greatest importance to keep the charging current within the permissible medium at starting, by some convenient method.

The plates in cells, no matter of what kind, should be so arranged that the resistance from every part of one plate to every corresponding part of the adjoining plate shall be equal, otherwise buckling will take place. The plates should also be so framed or held in place that they cannot shift.

An accumulator to remain in good health, like a human being, must be exercised gently and regularly; that is to say, the cells must be regularly charged and discharged with moderation. Most of the makers of lead plate batteries give very high *maximum* rates of charging and discharging for their cells, in fact many times greater than those mentioned in this chapter. It must be distinctly remembered that such high rates

are only allowable for short periods, and on exceptional occasions.

All modern batteries can be discharged from normal rate to three times this rate. In some types even as high as six or seven times the normal discharge. But the capacity rapidly decreases with the higher discharge. For instance, if a battery will give 70 ampères for ten hours, then for six hours 100 ampères can be taken, and for four hours 120 ampères.

There is no better test for ascertaining the condition of the battery than by the colour of the plates. When the accumulator is first started, the negatives are a yellowish grey, and the positives dark brown, spotted with a whitish or reddish grey substance. If the first charge is carried on long enough, this whitish material, being the objectionable sulphate deposit, disappears, and from this time the colour becomes the test.

The positives should be dark red, chocolate, or plum colour; but when fully charged they look like wet slate, nearly black. After a small discharge they regain their former appearance. If too much discharged, the white deposit reappears in patches. Frequently a reddish scale appears instead of the white deposit. The best way to describe this colour is to say that it has a venetian red tint. The presence of this scale to a novice is difficult to distinguish, because, being red, it is apt to be mistaken for the proper colour of the plates; but on close examination,

it will be found that it is really a coloured scale in patches not firmly attached to the plate. A careful observer will never fail to distinguish this appearance after it has once been seen. The negatives soon assume a pale slate colour, which darkens slightly as the charging advances. They are, however, always much lighter than the positives. The upper edges of the positive plates generally appear grey, but this is of no consequence if limited to those parts.

It is possible to become a *connoisseur* in regard to the colour of the plates, for a constant observer can tell their true condition; not only whether they are of a good or bad colour, but also know the exact amount of the charge they contain.

There is nothing special to add in respect to unpasted plates (beyond what has already been explained). All the instructions which have been given for charging a battery apply with equal force to these types.

It frequently happens, in all types, that the grid breaks at the edges; but this is of no importance, unless the fissures extend very far towards the centre, in which case there is a danger of the grid breaking and creating a short circuit. These fissures are more common with the plain lead type than with the other; but with the pasted ones they constantly appear when the battery has been in use for a long period.

Notwithstanding the losses necessarily incurred by

the use of the accumulator, the latter is an economy in private installations, and not less so for public supply in some instances. There is no need to run the engine and dynamo during the many hours when only a few lamps are required; also the plant may be smaller. Besides, the light is never cut off for a moment day or night, and a feeling of security exists from the knowledge that a breakdown need not be feared. Another advantage is that, during the cleaning of machinery or slight repairs, there is a sufficient reserve to insure light over the span when darkness would otherwise ensue, at great inconvenience to the household.

The following table of lighting hours has been drawn up by Colonel R. E. Compton, and is very convenient for reference.

It will be noticed that the hours from six a.m. till sunrise and from sunset till eleven p.m. for the whole year are 2,075, or say, in round figures, 2,000. These figures are a guide to the number of hours during which one or more lamps are required.

LIGHTING HOURS THROUGHOUT A YEAR OF 8,764 HOURS.

DAILY LIGHTING.	Jan.	Feb.	March.	April.	May.	June.	July.	August.	Sept.	Oct.	Nov.	Dec.	Total per ann.
From Sundown to 11 p.m., - - -	218	173	160	126	99	80	87	114	144	180	207	233	1821
From Sundown to 12 p.m., - - -	249	201	191	156	130	110	118	145	174	211	237	254	2186
From 6 a.m. to Sunrise	63	36	7	—	—	—	—	—	—	13	43	63	254

In London it would be fair to consider that in 120 days out of the year (in consequence of the fogs and darkness overhead) light is required between sunrise and sunset, so that artificial light would probably be needed for 2,600 hours per annum, and in some years as much as 3,000 hours.

Although the last table states the number of lighting hours at various periods of the year, no idea can be formed as to the time in the morning after which artificial light can be dispensed with and the hour in the afternoon when lamps become necessary.

The following table contains information on this point to a degree of accuracy sufficient for practical

TABLE

Showing to what hour in the morning lamps are required for each month of the year.

	Jan.	Feb.	March.	April.	May.	June.	July.	August.	Sept.	Oct.	Nov.	Dec.
Beginning of the Month, -	8.0	7.30	6.30	—	—	—	—	—	—	6.10	7.0	7.45
Middle, -	—	7.20	—	—	—	—	—	—	—	6.30	7.20	—
End, -	—	7.0	—	—	—	—	—	—	—	7.0	7.45	—

TABLE

Showing the time when lamps are required in the afternoon for each month of the year.

	Jan.	Feb.	March.	April.	May.	June.	July.	August.	Sept.	Oct.	Nov.	Dec.
Beginning of Month, -	4.0	5.0	6.0	6.30	7.30	8.0	8.15	7.45	6.45	5.30	4.20	4.0
End, -	4.30	5.30	6.30	7.15	8.0	8.20	8.0	7.0	5.45	4.30	4.0	—

purposes in London and its neighbourhood, since the hours given are based upon the time at which the sun rises and sets at Greenwich, and a correction must be made in regard to places where this hypothesis does not hold good.

The hours given in these tables are only approximate, being averaged over the portion of the month to which they refer.

Before closing this chapter, it is necessary to give an account of the best way to charge small cells, firstly, on arrival, and secondly, when in general use. By small cells it is understood to be those which are portable and have a capacity from say 10 hours up to a 100 ampère hours. As a rule, these cells are in boxes or trays, 2 to 5 in a group, giving from 4 to 10 volts. The makers generally give the capacity value, and the charging and discharging rate should be normally one-tenth of the stated capacity. Thus, if a cell is said to have 100 ampère hours capacity when charged, then 10 ampères should not be exceeded for charging; and for discharging, the same rate, but this latter may be increased on occasions to as much as double.

Small cells are sent out, as a rule, with the plates formed and discharged. It will, therefore, be necessary to fill them with the electrolyte, same in character as for larger cells, and to charge them for at least 10 hours. Then if "boiling" ensues, all is well, and the cells may be discharged. Some makers send the

cells out filled with water, which, of course, must be emptied on arrival and treated as just mentioned. Others send the plates unformed. In this case, some 30 to 40 hours' charging is required, and longer if the plates do not assume their proper colour, and "boiling" start properly. The simplest method to charge small cells off mains of 100 or 200 volts is to insert an incandescent lamp in one of the charging leads, such lamp passing the current required. If the current necessary is as high as 10 ampères, a "resistance" may be required, or, simpler still, 10 lamps in parallel each passing 1 ampère. In fact, where many batteries of small cells have to be charged, it is well to fit up a small switch board of say 10 glow lamps, each passing 1 ampère, and each lamp having a switch. In this manner, 1, 2, 3, up to 10 ampères can be obtained, according to the number of lamps turned on. Every care must be taken to connect the battery to the charging mains correctly by means of a pole-finder. A number of such small batteries may be charged at the same time in series, provided that their total voltage is 10 per cent. less than the pressure of the charging mains.



## CHAPTER IV.

### DISCHARGING.

THE normal discharging current may equal the normal charging current in all modern types of plates, and a discharge equal to 3 or 4 times normal can be given without injury to the plates, but the capacity is reduced almost in the same proportion, *i.e.* double normal discharge, half the normal capacity, three times normal discharge, one-third normal capacity, and so on up to the limit, that is, the maximum obtainable without the E.M.F. falling below 2 volts. Hence, when the discharge is very high over a long period, the battery is exhausted much earlier than under normal conditions. Moreover, it is found that the larger the discharge the lower the internal resistance of the cells at the time; so the accumulator, to a great extent becomes its own governor. This is a remarkable property, and may be comprehended in this way: there is practically no fall of E.M.F. for any discharge within the limits allowed, because the

internal resistance of the cells diminishes as the current increases. But for this property, batteries could not be employed for practical purposes, because their efficiency would be too low, and a regular pressure could not be obtained without much trouble and risk of failure.

The current starts at one point in the circuit, and returns to the same point; but, in its course, it gradually loses pressure, *i.e.* E.M.F. Consequently, the pressure of the current differs at every part of the circuit; and at those parts, where the work demanded of the current is heaviest, the fall of pressure will be greatest.

Since the E.M.F. of one cell is two volts, of two cells four volts, and so on, it is evident the total E.M.F. is obtained only between the ends of the battery. When testing one or two cells, low E.M.F. measuring instruments, or, as they are generally called, low-reading volt-meters, are employed. But such instruments would be destroyed, if used to measure a high E.M.F.; and one made to measure high E.M.F. would be unsuitable for low pressure, except in combination instruments, which are really equivalent to two or more separate voltmeters. It is with a low E.M.F. voltmeter that the state of each cell is examined.

If in any cell the pressure is below 1.9 volts, then it requires charging, for the residual charge has been reached; and, if the other cells are charged, it must

be cut out of the circuit during discharge and replaced when charging is renewed. Only, the connections are altered for the time being, the cell not being moved.

There must always remain about 2½ per cent. of the total charge the cell is capable of taking; otherwise troubles arise, so that the moment the E.M.F. of the battery falls below an average of two volts per cell, which indicates that this limit has been reached, charging must be resorted to.

When the plates are nearly discharged, that is, far below the minimum permitted, nearly all the paste on the positives is in the form  $\text{PbSO}_4$ . This soon decomposes into the higher sulphates which ruin the plates, and, apart from other consequences, cause them to buckle when charging is proceeding. It is therefore evidently imperative to keep a residual charge sufficient to give an E.M.F. of two volts per cell. In fact, after being fully charged, the cells may be steadily emptied to the permitted limit, giving practically two volts per cell the whole time. Then comes a rapid fall of pressure, soon reaching zero point. There is a great diversity of opinion as to the cause of a sudden fall in the pressure when a certain state of discharge has been reached. Some authorities think that the negative plates become slightly reversed when this phenomenon takes place: others say there is not the slightest foundation for the supposition. The most reasonable and probable

cause for the sudden drop of pressure is that given by Mr. Robertson, and referred to in the previous chapter.

Too quick a discharge buckles the plates, and a very sudden large discharge drives the paste out of them, although the current may be well within the maximum. Therefore, when motors, exceeding  $\frac{1}{2}$  h.p., are started, it should be done through a variable resistance, apart from the requirements of the motors themselves. For the same reason, large batches of lamps should not be simultaneously turned on. Quantities of gas, driven from the plates at the moment of sudden heavy discharges cause the injury. A large sudden discharge may be regarded roughly as one of 50 per cent. of the maximum. With plain lead plates, the risk of damage is far less.

Should a cell in the battery be dead (*i.e.* give no E.M.F.) from overwork, then, if not attended to at once, and cut out of the circuit during discharge, the outgoing current will pass through it and start charging the cell in the reverse direction; thus converting the positive plates into negatives and *vice versa*. This will naturally destroy the cell, because, when charging is commenced, the opposite action takes place; and, eventually, the plates sulphate, buckle, and lose their paste. A dead (*i.e.* worked out) cell will also produce a counter E.M.F. of two volts. The total loss of pressure will, therefore, be that of the cell itself plus the counter E.M.F.; in

other words, a cell, giving no E.M.F., lowers the pressure on the circuit equivalent to the removal of two good cells. But, if it be dead by reason of the plates touching or from any other cause, the loss of E.M.F. will only be that of the cell itself, since it sets up no counter E.M.F. in this case.

When a battery is left standing, many have found that large quantities of hydrogen gas are given off; whilst others have not found this to be the case in any great degree. If a large quantity of this gas be removed from the negatives, it seems highly probable that the latter are giving off a portion of their effective quality; and as a natural result the positive plates cannot be so much discharged: consequently, there must be a loss of storage, because the positives cannot be discharged so completely. It would, therefore appear that, if a battery is left standing for any considerable time, a great loss of storage must ensue, though insulation may be good. This, however, is contrary to the author's experience. He has found that hydrogen is given off from the negatives, but the amount of the gas so lost depends a great deal upon the condition of the plates, and that when they are in good order and well charged after standing for a month, the loss of capacity is very small. In fact, on starting charging, a very few minutes elapse before boiling sets in; which is a ready test for ascertaining whether there has been much leakage. The writer has also found that the escape of hydrogen from the

negatives is almost insensible a few hours after the charging has been completed. Colonel Crompton expressed an opinion that the action of light had some effect upon a cell, but Professor Ayrton conducted a series of careful experiments which proved the contrary. Consequently, if light has any action whatever in this instance, it must be insignificant.

With most types of plates, the electrolyte is found to discolour, generally assuming a slightly purple hue. In all cases discoloration of the electrolyte is due to foreign substances, which were present before the liquid was poured into the cell or derived from some soluble foreign salts existing in the plates themselves, usually the positives. These foreign salts are more frequently found in plates of the unpasted type. As already mentioned, in most cases permanganate of potash is the cause.

A rough rule for capacity is the following:—one hundred ampère-hours per *square foot* of positive plate (not surface). This is equivalent to fifty ampère hours per *positive plate*, in a section of the size most generally in use. Also the capacity may be approximately taken at twenty-two ampère-hours *per plate* in a section.

It is usual with accumulators to measure their capacity in “ampère-hours.” An ampère-hour means one ampère flowing for one hour.

All the foregoing remarks may be taken to apply equally to the unpasted type, which, however, has

the advantage of being able to withstand a heavier discharge without injury to the plates. The limit of possible discharge is shown when the pressure of the current begins to fall appreciably. These heavy discharges are not to be recommended as a general rule.

The author particularly advises purchasers of a secondary battery to discount manufacturers' working figures. It is well to deduct from the charging and discharging at rates at least 10 per cent. of the figures they quote; also to regard the available capacity at 25 per cent. less than that given. There is no doubt that the figures in the makers' price lists are possible, but naturally they state as good a result as can be obtained, and they do not guarantee that these values can be maintained year after year without fail. The writer's experience is that, if the allowances just mentioned are made when a battery is purchased, and are adhered to in practice (though the capital invested to do a certain work may be somewhat larger at the start), the final result is most favourable to the purchaser. Money, vexation, and inconvenience will be saved in a great degree.

## CHAPTER V.

### FAILURES, THEIR CAUSES AND REMEDIES.

THIS chapter is probably the most interesting to the majority of those who possess installations, because the batteries are generally put up by the makers. The theory has not an interest for everyone, but when difficulties arise in daily working a remedy is at once called for.

For the most part the remarks which follow may be taken to apply to the unpasted, as well as to the pasted, type of plate, except where it is evident from the context that one of the types alone is referred to. To deal completely with the pasted and the unpasted types separately would need so much recapitulation as to become confusing.

It cannot be too strongly impressed that, whether the plates are pasted or whether they are not, the chemistry and phenomena are the same, so that the rules to be observed for charging and discharging, as well as the troubles which may arise, are the same for



both. One distinction alone exists: in the pasted type there is paste which may become loose, scale, or fall out; whereas in the plain lead type scale only may separate.

There are two troubles which beset most accumulators, viz., buckling of plates and bad forms of sulphating. To these all other difficulties, with few exceptions, may be traced. Buckling is almost unknown in well-managed installations.

When cells are left to rest for a long period, they ought to be thoroughly charged; and once a month afterwards a good charge should be given them. This will prevent the plates from getting into bad condition in the event of total discharge by leakage and local action, which are always present in a small degree, even under the most favourable conditions.

If by any chance the positive plate should sulphate deleteriously, the action must at once be stopped or the battery will be spoilt. Bad sulphating is shown by the chocolate colour turning greyish all over the surface, or in patches, or the venetian red colour appearing, as mentioned in the preceding chapter.

The colour of the edges of the plates gives an indication of what is taking place over their surface; so that, if there is not a marked difference in colour between the positive and negative plates, a careful examination should be made. The results of bad sulphating are scaling, the falling out of paste, buckling, and short-circuiting, and, in the last case, the

grids generally become rotten; whilst the causes may always be traced to the acid solution being too weak or too strong, but more generally to the cells having been habitually over-discharged, or left standing for a long period with little charge in them. Also short-circuiting will naturally do this, since the plates become discharged. A leakage in the circuit may discharge the battery without the knowledge of the owner. Bad insulation of the cells themselves will produce the same result.

An easy test for the insulation of the accumulator is to wet the back of the hand with weak acid and place it against the shelves; should the insulation be faulty, a pricking sensation is felt, which becomes painful if 100 volts are used. Should higher voltage be employed, it is not safe to make this experiment. At 200 volts the shock is strong, but it varies with every individual; for whilst some people do not object to 210 volts, others cannot stand sixty, especially those who suffer from damp hands.

All currents may be regarded as more or less dangerous to the person after 250 volts, but the pressures of 60 to 100 volts, which are harmless under ordinary circumstances, may prove dangerous under peculiar conditions. For instance, a man may be on a pair of steps placing a new lamp in a fitting, and unexpectedly get a slight shock, due to leakage or otherwise, and then the start it gives him may cause a fall from the steps. It is always advisable to cut

both leads when anyone is attending to fittings or doing any work on the circuit.

To return to the cure for bad sulphating, a continual charging below maximum rate, half to start with, for a prolonged period, will gradually reduce the unhealthy sulphate to the healthy form, and finally charge the plates by conversion of the  $\text{PbSO}_4$  to  $\text{PbO}_2$ . The task is tedious, but it must not be hurried, or the positives are certain to buckle. Most of the white sulphate will fall off in scales, but should any stick between the plates it must be pushed down with a piece of wood or a flat strip of ebonite, the latter being the best. But on no account should a piece of metal or any other conducting substance be employed for this purpose. When white sulphate exists upon the positive plates, it shows that most of the oxide has been converted into  $\text{PbSO}_4$ . These sulphates are very bad conductors. Consequently, when the white sulphate is observed, it may be concluded that a great resistance is offered to the current doing its work, and is in a manner equivalent to the plates having a much smaller active area. The maximum charging current is, therefore, too large; but the current may be increased as the white substance falls off or disappears. If the sulphating has become very bad, these scales often separate from the plate carrying with them the blocks of paste which they overlie. This is very vexatious, for the capacity of the battery becomes much reduced by loss of active

material, and great trouble is experienced in getting from between the plates these pieces, which, if not removed, short-circuit the cell.

In the most recently improved cells, in which the plates are situated farther apart, any paste falling out will occasionally hang up between the plates, although it would appear at first sight to be impossible; so that absolute reliance must not be placed upon the statement of the makers that paste *cannot possibly* stick between the plates. It may occur in four ways. The first is, when the plates are in bad order they frequently lose their flatness, and, consequently, the original distance between them is no longer maintained. The second is that some samples of paste are apt to throw out short crystal needles, which arrest the fall of the paste. The formation of needles in pasted plates is sometimes due to the character of the paste itself. Extremely slow charging is apt to produce needles with all plates, when it is continued over a long period. This kind of charging may be described as ten per cent. of the permitted maximum. Thirdly, the opposite blocks of paste may so fall as to encounter one another. Finally, pieces of scale may separate and be of such a size that they cannot fall clear between the plates.

When a battery is first erected, it frequently happens that very large scales come off the positives. The plates in new cells must, therefore, be watched for a few weeks, and any scales that may be observed

between the plates should be removed. If this is done carefully, the trouble soon disappears.

When the plates are in a very bad condition, a good plan is to clear a little of the white deposit off each positive with a stick, and so offer some healthy surface to the current, lowering the resistance of the battery and facilitating the reducing process.

After bad sulphating the capacity of the cells must always be less, in consequence of the loss of some of the active material. Where the fault is great, the best plan is to clean the battery properly.

The cleaning of a battery consists in removing the sections from the cells (after a good charging), separating the sets of plates, and scraping the white deposit off the positives. There is no need to remove the plates from the lead strips, for by bending them apart plenty of room is allowed for manipulation. In cases where the plates cannot be parted, they must be reached as well as circumstances permit; and generally no difficulty occurs. The wire-brush material sold under the name of "carding" will serve to do the work satisfactorily. A piece of this is cut to six by four inches, and nailed to a block of wood half an inch thick, and having a handle, if found necessary, for reaching between the plates. The brush is now applied to the positives till they appear their proper colour, and they are finally washed with the electrolyte, and on no account with water, or

sulphating will set in immediately. This done, the cells are again made up, when the old solution may be used again, although it will generally be found more convenient to put in fresh electrolyte.

The cells are then ready for immediate charging, and they should be regularly overcharged and watched for some time. The cells also should be cleaned from any deposit. The old acid answers well for washing the plates with, and for placing the negatives in whilst waiting; for these, being wet, are injured by exposure to the air. Should this solution be employed a second time, it must be allowed to stand until it becomes clear before further use. (If the old acid is rejected, it may finally be used to destroy weeds on roads and paths, so that nothing need be wasted.)

There is considerable risk of accident from short-circuiting, if a cell is moved with the electrolyte in it. Therefore, unless skilled labour be employed, it is best to syphon off the liquid with a  $\frac{3}{8}$ -inch red india-rubber tube, filled with solution by dipping it bodily into a vessel of liquid and then keeping the thumbs over the ends to prevent escape, whilst it is applied to the cell. Under no circumstances should the tube be sucked in order to "draw the syphon," as this proceeding is highly dangerous, because of the poisonous and corrosive character of the acid and the liability to receive a shock in the mouth. So long as the electrolyte touches the plates there is

possibility of short-circuit. This must, therefore, be drawn off completely, and then no accident can possibly arise.

If the positives are past recovery, it is the cheapest to have a new set, which can be obtained from the makers at a very moderate cost in exchange for the old plates.

The process just described for cleaning a battery is employed for buckled plates, with the difference that these require to be straightened. This is effected by placing between every positive plate (or negative, if at fault) boards of such a thickness that all the plates are parallel and in the same position as when in the cell, or the connecting strip of lead will be bent or broken. The plates, with the interleaved boards, are then laid on their side upon the ground, and pressed till they are quite flat. A portable lever-press or a screw-press is generally used for this purpose. No attempt should be made to flatten by means of hammering, as this is sure to loosen the paste. As soon as the battery is reconstructed, charging should be commenced.

When the negatives are removed from the cells, they, on drying, become hot; and this is probably due to the finely-divided lead they contain oxidising in air. Negatives exposed to the atmosphere for a length of time especially if it be moist, show signs of blistering when in use. This is very troublesome, for the blisters frequently become detached in the

form of scale, which sticks between the plates, thus partially short-circuiting them, and eventually causing the positives to sulphate.

Blistered negatives often exist which do not drop the scale, and, in this event, no evil consequences follow; but the risk should not be incurred. With new cells the negatives often blister from careless manufacture. If a cell becomes completely exhausted or, by chance reversed, the negatives buckle; but, as a general rule, it is only the positive plates which are subject to this trouble.

In large sections not mounted in frames, the lower ends of the negatives sometimes buckle with the forming charge. This has already been referred to. It is only necessary to bend them straight, with slips of wood, after a few weeks of use, when the trouble disappears.

It is always advisable to charge well before cleaning or straightening plates, because the air does not then act so prejudicially upon them.

If the positives sulphate badly, the surface becomes very hard; but when they are in good order the surface of the paste, as well as that of the grid, is soft, and the colour comes off readily on the finger like pigment.

When the positives get into a very bad state, the negatives are generally in a similar condition.

Much loose scale, from positive or negative plates, may be removed by taking the sections apart and



agitating the sets of plates, separately, in a cell or tank of the electrolyte.

Buckling, apart from the causes indicated in the preceding chapter, may be produced by too high a charging or discharging rate. It also often arises from pieces of loose paste sticking between the plates, which cause an unequal resistance between the surfaces, so that expansion and contraction are not symmetrical. When this occurs, the plates are often of a good colour. In all cases the framework, or other means employed to keep the sections together, must be so made as to allow for the expansion of the positives. The allowance need be very small, since the plates are generally put together in the expanded condition—*i.e.*, in the unformed state; but slight after-variations should be taken into account. Sometimes plugs of paste drop out when everything appears right, and the cause is usually found to be that a large discharge has been taken suddenly. Consequently, this proceeding should be avoided.

If a film appears all over the inside of the cell, partially obscuring the plates, the water mixed with the acid has been impure. When this occurs, much inconvenience arises from inability to see the edges of the plates properly; but no actual harm is done, and it can be entirely avoided by allowing the solution to settle after mixing, and baling it out, leaving the sediment undisturbed. A slight quantity of powder at the bottom of the pots will always be

found; this consists chiefly of the white sulphate removed during the first few chargings.

With ordinary care the author has found that, after working cells for three years, the loss of paste is so small as hardly to be worth mentioning. Some experimenters have for the same period found a considerable weight of deposit at the bottom of the cells. It may be concluded either that the batteries were not properly managed, or the sections were left standing in the air for a considerable time before putting them to work, or that the plates were faulty in their manufacture.

The plates must never touch the bottom of the cells. Therefore, care should be taken occasionally to observe the condition of the bottom block or frame, and observe that the deposited scale does not reach the plates.

The construction of the sections now generally employed is such that both sets of plates cannot be short-circuited by deposit in the cell. If the wooden support should give way from any cause, there is the chance of the glass being broken.

A temporary cure for plates buckling is the insertion of glass strips or wooden wedges, to prevent adjoining plates from touching; but the cause must be removed at the first opportunity and the plates straightened.

It sometimes happens that the dynamo leads have been wrongly connected, in which event the plates

throughout the battery become reversed; the negatives change to chocolate in colour, and the positives to slate. Such a mistake ought to be carefully guarded against. Should it occur, there is only one remedy, namely, to discharge the battery completely, through a resistance frame or through the lamps, see that the maximum discharge allowable is never exceeded. This resistance may be reduced as the E.M.F. of the battery becomes less. When the accumulator gives no E.M.F., or a very low one, the dynamo wires must be correctly joined up, and charging should be started very slowly at first and with a resistance, for a time, in one of the dynamo leads to keep the current small, since there is little or no counter E.M.F. to overcome, till the cells charge up in right way. Running the dynamo slowly will answer the same purpose as the insertion of a resistance, but the latter is more convenient. It will take a long time to get the plates into good order again, and perhaps many troubles will ensue, each of which must be treated in the proper way; but matters soon mend, provided the mistake be discovered early.

A resistance frame called, for brevity, "a resistance," consists of a frame of wood with a number of coils, either of iron, german silver, or platinoid wire, stretched across it. The whole contrivance appears like a frame, containing a large number of spiral springs placed close together. The frame is sometimes made of metal, in which case the coils are

insulated from it by means of slate, or porcelain, supports. Arrangements exist for permitting the current to flow through one or more of these coils, so that the opposition to the current may be varied at will. The wire is proportioned in its section so as to carry the desired current.

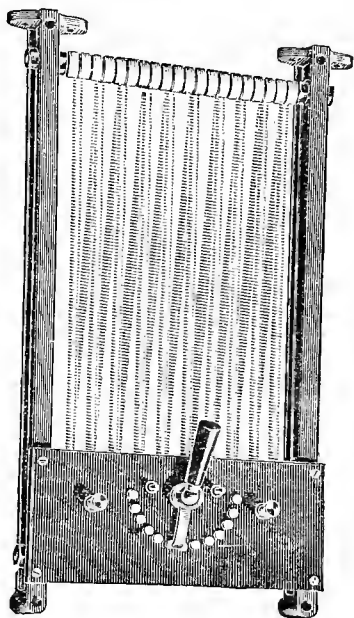


FIG. 36.—RESISTANCE FRAME AND SWITCH.

A resistance frame of modern type shown in Fig. 36.

Platinoid wire possesses so many advantages over ordinary metals that its properties ought not to pass

unnoticed. For the same length and size of wire the resistance of platinoid wire is almost double that of german silver. Platinoid does not oxidise appreciably in air, and its resistance for various temperatures is fairly equal; it is also exceedingly hard. The wire is also very strong, and its cost is but a very little more than that of german silver. Therefore, for any definite resistance, far less platinoid wire is required than if german silver were used. The word platinoid would seem to imply that platinum is present in its constitution, but this is not the case. There is a small amount of tungsten in the alloy. Its melting temperature is high, which renders it very suitable for use in resistance frames. The chief trouble encountered with such frames is that, in course of time, the metal is apt to become crystalline and breaks. This may be due to three causes, or to any, or to all of them combined: (1) The passage of the current; (2) the high temperature to which the wire is subjected; (3) the natural process of oxidation. German silver is especially liable to this defect. Where room would admit of it, by far the best material for use in artificial resistance is galvanised iron-wire. But to produce an equal resistance in replacing platinoid, about twelve times the length of wire of the same gauge is necessary. Liquids are sometimes used as resistances.

If a cell gives no E.M.F. from any cause, except complete short-circuit, then the discharging current

has the effect of charging such a cell the reverse way, and the plates become reversed. The proper course to pursue is always to disconnect such cells, when discharging, by bridging them over with a wire and to reconnect when charging. In time the cell will become charged equally with the rest, and it can then be permanently replaced. To cut both connections of such a cell is unnecessary; to break the circuit at one end is sufficient.

Proceed in this way: Disconnect the positive strip of the dead cell from the negative of the next, and clamp one end of a wire to the negative strip of the dead cell (equivalent to positive of the adjoining one) and attach the other end of the wire to the negative strip of the next cell, which has just been disconnected.

When the charging commences, be careful to remove this wire before connecting up, otherwise the cell will be short-circuited through it, damaging the plates and perhaps causing an accident by fusion of the wire, if the latter is too small. The whole operation may be facilitated by the use of a two-way switch, with a break between the contacts, suitably connected, by which means the cell can be put in and out of the circuit at pleasure.

All conductors in the accumulator-house should be so placed that, if the insulation wears off by the action of the acid and of the fumes, short circuits will be impossible. The leads may be carried on porcelain

insulators, and every wire should be kept well apart.

It is very desirable that all the leads should be painted with Griffiths' anti-sulphuric acid enamel, as it will be found a great preservative.

Never add concentrated acid to the cells, as the grids will soon become rotten if this is done. Never test a cell for E.M.F. by "flashing," which means taking a short wire, placing one end firmly on the positive strip of a cell and rapidly touching the negative strip (or *vice versâ*), in this way producing a flash if the cell has life. It is the old method of testing, which, if frequently resorted to, soon spoils the plates, and no scientific result is obtained. The proper way to test is with a lamp or voltmeter, as before described, combined with the acidometer.

When the plates are badly sulphated, the internal resistance of the cells is greater, and consequently the E.M.F. for daily use is much lower. Their capacity, also is less. Charging continued till boiling occurs, without further observation, may result in erroneous conclusions, for clearly the less the capacity of the plates the sooner will the phenomenon occur, and everything is supposed to be in good order; whereas a serious fault may really exist, for the plates may be in bad condition, or much paste lost, or many cells dead. The boiling in the latter case arises from the charging current being too great, since much counter E.M.F. has been removed. Again, it may

happen that no amount of charging causes the cells to boil, indicating that nearly all the paste has fallen from the plates. Even in this condition the cells act as regulators to steady the light, but they have scarcely any capacity.

An accumulator only regulates to a very small degree, say, for variations of pressure not exceeding 2 per cent. when the current flowing into the mains equals half the maximum discharging current of the battery, and  $\frac{1}{2}$  per cent. only for a current to the lines equal to maximum discharge. For large variations of current pressure, although the battery improves matters, the regulation is very imperfect, and can be seen at the lamps.

If at any time the plates of a fully-charged cell are taken out of the electrolyte, then, on making up the cell again, the s.g. of the liquid put in should be the same as it was before the removal. If acid of a lower s.g. is used, no amount of charging will appreciably raise its density, because the  $\text{PbSO}_4$  has already been reduced to  $\text{PbO}_2$  on the positives as far as was possible. Consequently but a very slight further chemical action can take place in the electrolyte.

At all times when a cell is charged as much as possible, whether the plates are in good or bad order, a point is arrived at when the acidometer indicates no further change in the s.g.

Grids are made of lead or alloy of lead and



antimony, the proportion of the latter being 10 per cent. This alloy is much harder than lead, and apart from ordinary advantages there is one which claims particular attention, and that is the possibility of repasting the plates when required. The first expense of a battery is so large, and the renewal of the whole of the plates in the cells so expensive, that it pays the owner to repaste his plates whenever necessary. With proper attention and fair usage, years may elapse before this is required; but the manner of proceeding is described for the benefit of those who may wish to act upon the suggestion. The value of the process may be estimated when it is stated that the author had a battery of fifty-four cells which lost most of the paste, and its capacity became very small. The whole accumulator was repasted by unskilled labour for an expenditure of about ten pounds, the result being that the battery was as good as new. Sometimes only a cell, here and there, wants renovating instead of the whole set.

Proceed as follows:—Take the sections to pieces and spread the plates a little when the construction admits of this being done. Start with the positives, and mix up a stiff paste of red lead and  $\text{H}_2\text{SO}_4$ , one part commercial acid to two parts water. The paste eventually assumes a dark reddish-brown colour, and more acid must be added until all appearance of red lead is gone. The paste then is chiefly composed of  $\text{PbSO}_4$ . It is possible to buy  $\text{PbSO}_4$  pure, and it is

well to do so since it is less impure than a mixture of red lead, which generally contains much carbonate. The spreading of the plates allows the hand to reach every part of each grid. The paste is best laid on with a small wooden board, and the surplus scraped off with a piece of iron-hooping. The plates are now bent back to their normal position, and set aside to dry. The paste should then be perfectly hard and adhering; if not, its consistency is at fault. A few trials will determine the point; a twenty-four hours' drying in a moderate temperature is sufficient. The plates are now ready. The negatives are treated in the same way, only the paste is made with litharge. The sections are now made up, placed in the cells, and all is made ready for charging. Probably thirty hours or more will be required to form the plates, after which every hour of charging is storage, when the chocolate or plum colour of the positives and the familiar appearance of the negatives are soon attained. Sometimes the forming is far more rapid.

Repasted cells must be cut out during discharge until they boil, and in no case should a repasted battery be discharged till all cells boil.

It is possible to paste the positives with  $\text{PbO}_2$  purchased under the name of puce-coloured lead, in which case ready-formed charged plates are made at the start. It is found by many persons that the  $\text{PbO}_2$  paste fails and soon falls out; but this has not been the experience of the author. There is a

physical difference between pasting with  $\text{PbSO}_4$  and  $\text{PbO}_2$ . In the first case the substance is laid on in the expanded form, and in the latter in the contracted state. If the manipulator can succeed with  $\text{PbO}_2$ , there is a great saving, since the cell is ready for a small discharge at once. Repasting can be accomplished with economy only when the grids are not rotten. Some experimenters obtain better results by pasting both positives and negatives with red-lead paste; others paste both sets of plates with litharge.

Most modern sections containing a large size of plate, have the positives of the formed type, and negatives pasted. Hence repasting is rarely required. But small cells, so much in use for X-ray work, on motors cars, etc., often have both kinds of plates pasted.

Vulcanized and pure india-rubber, if of good quality, does not deteriorate in the acid, but, if bad, it falls to pieces in a short time; indeed, even a few hours may break it up. Very commonly vulcanized india-rubber is adulterated with lead, on which account its good non-conducting properties are greatly impaired, in consequence it has frequently been found to fail as a good separator.

Celluloid is often employed for the pots of small cells, also in strips, blocks, or perforated, crinkled sheets for separators. Celluloid varies greatly in character. Some kinds absorb moisture freely, and even become soft; other kinds shrink and warp.

Care should, therefore, be used in its selection. To repair and "solder" celluloid acetone is employed. This liquid should be used sparingly since it dissolves celluloid. Acetone with a little celluloid dissolved in it makes an excellent repairing material. Failing this liquid, common vinegar may be employed in emergency cases

It may be of importance to some persons to know the best means to adopt when it is desired to transport a battery to a distant place, after having been in use, so that the plates may not be injured. The battery should first be charged, then the sections should be taken apart and the plates pressed together, either wet or dry, so that only one face of each of the end ones is exposed to the air. Each batch can then be wrapped in oiled brown paper. When it is not possible to follow this course, the sections should be kept from contact with the air as far as possible by enveloping them in oiled paper, and the intervals between the plates should be stuffed with hay packed in oiled paper. When the battery is put up again, it is treated in the same way as if it were a new one. If this method of transporting be adopted, no harm will be done to the plates; but it will be advisable to set the cells up again as soon as possible.

There is little to be said regarding unpasted batteries, for, beyond clearing any bad scales which may cause short-circuits and occasionally straightening buckled plates, there is nothing to be done.

Spongy-lead plates are generally treated with nitric or other acid, and the frequent non-success of this type has been attributed by many to the fact that the acid has not been entirely washed out before the plates are brought into use. Some persons even go so far as to believe that spongy-lead plates cannot possibly be freed completely of the acid, but this is an error.

Spongy-lead plates may scale, blister, and break away in the same manner as the pasted ones; and the causes are identical. All these bad results may, with proper management, be avoided.

So much has been said in this chapter on failures that it might be supposed an accumulator was simply a source of annoyance. This is the case only where the accumulator is not watched and any little fault at once remedied. As a rule very little trouble is given, and none at all if competent persons occasionally view the installation. In order to bring all the facts concisely before the reader, the final chapter is in the form of a summary.

## CHAPTER VI.

### TESTING A SECTION.

It is no uncommon occurrence for an expert to be called upon to test a cell for its charging and discharging current, its capacity per pound of lead, and wearing qualities, also as to the best specific gravity to be given to the electrolyte. A few words on this subject may prove useful. To speak the actual truth, there is no method at present known for testing a cell satisfactorily in a short space of time. The author has frequently been called upon to make such tests, and the task has always been undertaken with great hesitation, seeing how often the best known experts have erred in making these rapid investigations. An attempt will be made to show the best way of finding the results sought for, when time is no consideration. In doing this, it is best to take several cases; and in all instances let it be assumed that the sections are built up of plates made of lead of a pasted, or unpasted, or crossed type. In giving the instructions

it must be understood that minute details are omitted, for amateurs will not be called upon to do this class of work.

CASE I.—The cell to be tested has its data given by the makers, they having already experimented largely to discover what suits their plates the best; and the object in view, therefore, will be to verify their statements. It may, in such a case, be presumed that the density of the electrolyte as given will be fairly correct and need not be further questioned. It may be assumed also that the maximum charging and discharging currents stated will likewise be correct, at any rate for short periods. The points, consequently, which remain to be ascertained are the best charging and discharging currents for practical purposes. These latter being known, there is no difficulty in making the deduction of the capacity per pound of lead. The more the plates are charged and discharged without undue strain, the larger will be the capacity until a working maximum is reached. Consequently, the capacity will vary in accordance with the previous usage to which the section has been subjected; and also for rapid discharges the capacity is always less than for slower discharges.

Proceed to test, for the charging and discharging currents, thus: For a period of, say, one week, charge and discharge daily at the rates given by the makers; charging until the cell boils, and discharging equivalent to one-half of the given capacity. If at

the end of this period all is right, continue in the same way for another seven days, but discharging equivalent to two-thirds of the capacity given by the manufacturers. For another seven days continue in the same way, but discharge to three-quarters of the stated total capacity. If at the end of this period—viz. three weeks—the plates appear in perfect order, it may be assumed that the section has fulfilled what has been promised for it for a short duration.

It will be now well, for a period of three months, to charge and discharge at the rate of 10 per cent. less than the given maximum, and to discharge about three-fourths of the given capacity. This need not be done daily, but say twice or three times a week over the three months. If, after this period, nothing shows itself to be wrong, the cell may probably be used for many years with the method employed over these three months, for it is never desirable to work to the limits. The next step is to ascertain the capacity with heavier discharges. It will only be necessary to discharge at increasing rates of, say, 10 per cent. at a time, observing the interval which passes between the beginning of the discharge and when the E.M.F. drops to a considerable extent. This will show the capacity in every case for given discharging currents, assuming always that the section has passed through the three weeks' treatment, first mentioned. These discharging rates may be increased enormously, but it will be found that the



E.M.F. will fall considerably. It will, therefore, be necessary to make these observations with a voltmeter, and to consider that the maximum discharge has been reached when the voltmeter reads 1.9 volts. When any fixed discharge has been decided upon, the experiment should be repeated again and again for, say, a dozen or two dozen times, to observe the effect on the plates; and then, if nothing is found amiss, the section will bear this treatment.

To ascertain the heaviest charging current that may be used, it will only be necessary to increase this current until the liquid begins to effervesce considerably, for at this point it is indicated that the surface of the plate is insufficient for a current to work upon, and is therefore doing part of its duty in decomposing the electrolyte. When the maximum charging current has been settled, it should be employed for at least two or three dozen times in order to observe the effect it may have upon the plates, the plates always being discharged to at least one-half of the estimated capacity before starting their charging.

It must always be borne in mind, when cells are employed for heavy charging and discharging, it is rare that they last as long as when used more gently. When they are employed with the milder treatment, six, or even twelve months is not too long for ascertaining their probable durability to extend over years.

CASE II.—No data given. Here the density of

the electrolyte has to be ascertained. It is well known that with lead plates of any kind the acid solution should never have a s.g. less than 1.130, and never exceed 1.220. It is practically settled by experience that the electrolyte should not be lower than 1.150 in the discharged cell, nor higher than 1.210 in a charged cell. Therefore, it will be safe to use an electrolyte, to start with, of 1.150. When the plates have been charged and discharged many times, say, thirty, and the electrolyte does not become denser, when the plates are charged, than, say, 1.200, it indicates that probably it would have been better if the first acid had been 1.160, instead of 1.150; for in this case the liquid, when the plates are charged, would rise to about 1.210. The reason why it is desirable to get the electrolyte up to 1.210, when charged, is that the stronger the electrolyte the greater the E.M.F. (up to a certain point); but if the density considerably exceeds 1.220 the probability is that the lead plates will be attacked by the solution.

To ascertain the charging and discharging currents the plates themselves must be examined to see if their construction is good (in accordance with remarks made in previous chapters), and if they are very porous; in which case both these currents may be taken as equal. Otherwise the charging current will probably be found 20 or 30 per cent. less than the discharging current. Assuming that the plates to be

tested are not positively faulty, a charging rate may be fixed from the figures stated in an earlier chapter, calculated by superficial area. All the remaining tests may be made in the same way as mentioned in Case No. 1. If the plates are faulty, they will show it at a very early stage, probably after ten or twelve chargings and discharging.

GENERAL.—There are some other points to be taken into consideration besides those which have been discussed. Speaking generally, they are the following :—

1. Whether the plates are of good shape.
2. The sections properly built.
3. That any deposit at the bottom of the cell shall not short-circuit the plates.
4. That the plates may be easily taken apart.
5. That they may be packed and may travel without being liable to injury.
6. That one section may be conveniently connected to the next.
7. That the positive and negative plates, lugs and strips are so situated that there is no undue risk of short-circuiting.
8. That they can be easily put in and taken out of their pots.
9. That the plates can be easily examined.

All these points and many others have already been discussed, and, therefore, to enter more fully into them would be simply to recapitulate.

It is often desirable, after a section has been in work for some time, to remove one or two plates and submit each one to a careful survey with a magnifying-glass to see if there is any tendency for the plate to crack or break; also to break up the plate and observe the appearance of the fracture, which will serve as a guide to ascertain how the formation extends from the surface towards the interior, or *vice versa*.

It is well known that thick positive plates possess practically no advantage over thin ones, although the former carry more paste. For mechanical strength the positive should be of a certain thickness, increasing with the area of the plate, and experience determines the proper thickness to be given. When a positive plate is charged, let it be supposed that the whole of the paste is in the peroxide state; then, on discharging, the surface first becomes sulphated, expanding during the process. In a short time this continued process of expansion, from the surface inwards, at last renders it impossible for the electrolyte to penetrate to the interior, or only in a very small degree.

The fair conclusion is that, if the paste be mixed with some other substance, so as to alter the mechanical structure by permitting the expansion to take place, and at the same time allow liquid to pass, the thicker a plate is made the greater will be its storage capacity. Possibly sand, powdered coke, or

other such material mixed with the paste would improve the plate; or some salt, which will dissolve out, still leaving the paste solid. Common salt, or soda, in small quantities, might produce the desired result.

## CHAPTER VII.

### SUMMARY.

ALWAYS charge the cells until they boil well. Never allow the battery to run down till its E.M.F. is below the average of two volts per cell. If this should occur when it is known that the charge is not low, an examination of every cell should be made. The acidometers in the cells, and colour of the positive plates, give an approximate idea of the state of the charge, if they are intelligently observed. Examine the plates every few days, by noticing their colour and other characteristics. No current-meter is of service to measure the charge remaining in the accumulator, since this instrument takes no account of the leakage which occurs before reaching it, nor of local action. It is desirable to use two ampère registering meters, one for outgoing and one for ingoing current. The amount of ampère hours put into the battery should exceed the ampère hours taken out by 10 per cent. Under these conditions,

all is likely to go well. In practice this means: one meter gives the ampère hours taken out of the cells, and it is known the number of ampère hours the engine can put in per hour, hence the number of hours to run can be estimated to charge up. As soon as only 25 per cent. of the total charge remains in the cells, the E.M.F. rapidly falls on further discharge. Precautions should be taken against too large a current flowing when charging is commenced, by inserting a resistance, or by means of an automatic governor; also, provision must be made against lamps being injured when they are turned on during charging hours, or the moment charging is completed. The instant any fault is noticed it should be remedied at once, and any dead cell cut out immediately. Do not charge longer than necessary, but see that all the cells boil well; if any are much behind, ascertain if there is any obvious cause for this. Half an hour to an hour overcharging is advisable. Occasionally examine the insulation. Observe that the liquid in the cells does not become warm during the charging. A *very slight* rise of temperature always takes place. All measuring apparatus should be compared with standard instruments periodically, so as to avoid falling into errors which may prove destructive to the plates. Feel all connections and switches every now and then, to see if they become warm.

Do not take advice for a remedy from the first person who gives it, before receiving an assurance

from some competent authority that there is value in the recommendation. Amateurs often act in the former way, and generally the result is that a heavy penalty has to be paid, but, unfortunately, not by the individual who caused the mischief. Possessors of an accumulator should not at any time spare money in sending for competent persons to set any fault right, for an apparently trifling matter becomes very serious in a short time, and by the course suggested much good money is saved and vexation avoided. Above all it must be remembered that no rules unmixed with brains are of the least service.

It is within the author's knowledge, as one result of the publication of this little book, (imperfect as it must necessarily be, with the changes which take place from day to day,) that a very large number of installations have been erected. On the other hand, a few cases have been brought to the notice of the writer where persons intending to use the electric light have been frightened out of the attempt after perusing these pages; because they have brought themselves to believe that the trouble incurred by its adoption will prove greater than the advantage. He therefore wishes to address a few words to such timid readers.

The object of this work is twofold: firstly, to give a general survey of the subject, it being always presumed that his readers have already acquired a certain amount of technical knowledge; secondly, to cite, as



far as possible, every conceivable case of failure and to state the remedy. It might, therefore appear that the whole subject is beset with failure and has no elements of success. It is clear that a remedy for a failure is the very thing that experts seek. No book would be complete that did not deal with these points, and up to the moment of writing there seems to be no work treating of these matters in particular.

The present book has produced a large correspondence chiefly relating to failures and accidents. Much gratitude is felt by the author for the information these letters convey. Even though a particular difficulty may be exceedingly rare, still it was considered worth while to report respecting it, and to recommend a remedy for the benefit of other persons.

Let the nervous reader imagine that the author, instead of writing about electricity, had published a book describing the various processes that an individual goes through, from, say, the moment he gets out of bed in the morning to his sitting down at breakfast; the pages that such a description would fill would be tenfold the number occupied in the present work. Let every little mishap that might occur during the process of washing and of dressing be set forth, as well as the remedy. There would naturally be included in an account of that kind such possibilities as a tooth-brush bristle finding its way into the throat and producing inflammation, which might lead to serious consequences; and even such trifles would

have to be mentioned as the stitching in clothing coming undone and the necessity of putting it to rights again. With such a deterrent picture before him, he must decidedly elect either to remain in bed for the rest of his natural life, or to dispense with clothing and the duties of the toilet altogether.

## INDEX.

- Accumulator, charging, 76.
  - dynamo leads, 150.
  - exhausted, 170.
  - for general uses, 32.
  - for small work, 27.
  - for traction, 29.
  - House, Broomhill, 86 and *Frontispieces.*
  - description of, 67.
  - floor of, 70.
  - inventor of, 38.
  - light type, 30, 32.
  - losses, 129.
  - moving of, 160.
  - old, 125.
  - regulating, 156.
  - rules, 42.
  - sections, 43.
  - starting of, 72.
  - use of wood in, 45.
  - ventilation, 71.
  - weight of, 30.
  - wrongly connected, 151.
- Acidometer, 80.
  - Hicks, 81.
  - Holden, 84.
  - Pipette, 82.
- Acid, persulphuric, 104.
- Apparatus, 15, 18.
- Battery, 33.
  - cleaning, 145.
  - left standing, 137.
  - purchasing a, 139.
  - re-charging of a cleaned, 146.
- Batteries, primary and secondary, 4, 5.
- Boiling, 91, 120, 121, 124, 156, 170.
- Books for reference, 37.
- Buckling, 126, 136.
  - temporary cure, 150.
- Cell, 33.
  - moving with electrolyte, 146.
  - pressure of, 47.
- Cells, advantages, 118.
  - Cadmium, 58.
  - capacity, 138, 145.
  - chemical action, 102.
  - chloride, 52.
  - connecting, 45, 48, 66.
  - dead, 136, 153.
  - how proceed, 154.
  - description of, 23.
  - D.P., 53.
  - dry, 35.

## Cells—

E.M.F., 92.  
     apparatus for find-  
         ing, 92, 93.  
     when discharged,  
         133.

E.P.S., 51.  
     film over glass, 149.  
     glass, 60.  
     glass slips, 84.  
     how placed, 65.  
     kinds of, 34.  
     left at rest, 141.  
     lifting, 69.  
     limit of E.M.F., 134.  
     Lumford, 54.  
     material of, 36.  
     method of connecting, 48.  
     method of perforating, 54.  
     Niblett, 55.  
     N.S., 55, 56.  
     passage of, 113.  
     Peto-Radford, 56.  
     primary, 35.  
     resistance of, 102, 117,  
         133.  
     setting up of, 60.  
     small, 131.  
     solid, 58.  
     spray preventing devices,  
         85.

Tudor, 52.

Celluloid, 159.

## Charging, 91.

    chemical process, 99, 100,  
         101.  
     constant current, 97, 120.  
     current, 95, 96, 126.  
     E.M.F. of, 96.  
     makers' instructions, 118.  
     over-, 121.  
     prolonged, 124.

## Charging—

    residue of, 135.  
     small cells, 132.  
     time, 98.  
     too large a current, 122.

Clamp device, 69.

Clamps, 68.

Clothing, 71.

Conductors, 154.

Contents, xi.

Current, dangerous, 142.

    meter, 170.

    passage of, 13.

    passage through wires, 14,  
         15.

Discharging, 127, 133.

Distribution, methods, 18.

    parallel, 19.

Dynamo, 8.

    alternating current, 12.

Electricity, development of,  
     21, 23.

    practical, 2.

    production due to, 2, 13.

Electrolyte, 36.

    adding liquid, 155.

    addition of water, 124.

    and acidometer, 156.

    discoloured, 119, 138.

    doctoring, 78, 80.

    filling in cells, 77.

    mixing, 77.

    purchase, 79.

    specific gravity, 77.

    strength of, 76.

    strips connecting, 119.

    warm, 171.

Failures, 140.

Faure, 37.

- Grids, 157.  
     breakage of, 128.  
     rotten, 142.
- Hand saw, 71.
- Illustrations, List of, xiii.
- Indiarubber, 159.
- Insulation, test for, 142.
- Insulators, 60.
- Introduction, 1.
- Junction, hot, 66.
- Lamps, arc, 15.  
     incandescent, 16.  
     per h.p., 20.  
     pressure for, 18.  
     resistance of, 20.
- Lighting hours, 129, 130.
- Litharge, 115.
- Motor, 17.
- Overcharging, 92.
- Plates, 33.  
     alloy for, 42.  
     appearance of Positive, 126.  
     bad condition, 145.  
     blistered, 148.  
     buckling, 136, 141, 147, 149.  
     buckling in large sections, 148.  
     capacity of, 26.  
     character of, 27.  
     chemical action, 123.  
     colour of, 127, 141.  
     deformation, 98.  
     denomination of, 36.
- Plates—  
     discharged, 135.  
     distance between, 144.  
     Elwell-Parker, 41.  
     for heavy charges and discharges, 28.  
     falling scale, 144.  
     insulating, 65.  
     joining together, 65.  
     lead and pasted, 95.  
     lifting, 64.  
     loss of paste, 123.  
     negatives removed from cells, 147.  
     pasted, 38.  
     plain lead type, 41.  
     Planté, 37, 39.  
     Positive and Negative, 47.  
     Positives pasted ready charged, 158.  
     Positives sulphated, 148.  
     Positives worn out, 147.  
     re-pasting, 157.  
     shape and manufacture, 39, 40.  
     size of, 96.  
     space for bottom, 150.  
     sulphated, E.M.F. of, 155.  
     sulphating, 141.  
     types of, 36, 37.  
     unpacking, 65.  
     unpasted, 160, 161.
- Pole finder, liquid, 75.  
     paper, 75.  
     indicator, 72, 73, 74.
- Pots, how placed, 65.
- Preface, v.
- Radium, 21.
- Resistance frame, 151.  
     of sulphuric acid solution, 111.

Scale removing, 148.

Section, testing a, 162.

Sections, 43.

building up of, 43.

cleaning, 62.

forming of, 46.

large, 99.

moving of, 156.

packing of, 62.

points desired, 167.

putting in cells, 62.

size of, 93, 94.

very large, 65.

Shelves, 60.

high, 65.

Soda caustic, 121.

Spanners, 69.

Storage, loss, 102.

Sulphates, high, 116.

Sulphating, cure for, 143.

Sulphuric acid, diluted, conductivity, 117.

solutions, resistance of, 111.

Summary, 170.

Terms, Index of, xv.

Theory, necessity for, 22.

Robertson's Paper, 103.

Varnish, anti-sulphuric, 68.

Ventilation, Accumulator House, 71.

Voltmeter, 134.

Wax paraffin, 61.

Wire platinoid, 152.

# Whittaker's Practical Handbooks.

---

**Practical Electric Light Fitting.** A Treatise on the Wiring and Fitting up of Buildings deriving currents from Central Station Mains, and the laying down of Private Installations. By F. C. ALLSOP. With 242 Illustrations. 5s.

**Electric Wiring, Fittings, Switches, and Lamps.** A Practical Book for Electric Light Engineers, Wiring and Fitting Contractors, Consulting Engineers, Architects, Builders, Wiremen, and Students. By W. PERREN MAYCOCK, M.I.E.E. With 360 Illustrations. 6s.

**Electric Wiring Tables.** A Collection of Original and carefully verified Tables for the use of Electrical Engineers. By W. PERREN MAYCOCK, M.I.E.E. Waistcoat Pocket size. Leather, gilt edges. 3s. 6d.

**Electric Lighting for Marine Engineers;** or, How to Light a Ship by Electric Light, and how to Keep the Apparatus in Order. By S. F. WALKER, M.I.E.E. With 103 Illustrations. 5s.

**The Dynamo, Its Theory, Design and Manufacture.** By C. C. HAWKINS, M.A., M.I.E.E., and F. WALLIS, A.M.I.E.E. With 413 Illustrations. 15s.

**Electric Lighting and Power Distribution.** An Elementary Manual of Electrical Engineering. By W. PERREN MAYCOCK, M.I.E.E. Vol. I., with 231 Illustrations, 6s.

Vol. II., with 407 Illustrations, 7s. 6d.

**Insulation of Electric Machines.** By H. W. TURNER, A.M.I.E.E., and H. M. HOBART, M.I.E.E. With 162 Illustrations. 10s. 6d. net.

**Electricity in Our Homes and Workshops.** A Practical Treatise on Auxiliary Electrical Apparatus. By SYDNEY F. WALKER, M.I.E.E., M.I.M.E., A.M.I.C.E. With 143 Illustrations. 6s.

**Alternating Currents of Electricity and the Theory of Transformers.** By A. STILL, A.M.Inst.C.E. With 60 Illustrations. 5s.

**Electricity Supply, Commercial and Business Aspect of.** A Practical Handbook for the use of Municipal Electrical Engineers and Members of Municipal Electricity Committees. By A. H. GIBBINGS, M.I.E.E. 6s.

---

*Catalogue of Works on Electricity, Engineering, &c., post free.*

WHITTAKER & CO., 2 WHITE HART STREET, PATERNOSTER SQUARE,  
LONDON, E.C.

# Whittaker's Practical Handbooks.

---

**Galvanic Batteries.** Their Theory, Construction, and Use. Comprising Primary, Single, and Double Fluid, Gas and Secondary Batteries. By S. R. BOTTON. With 144 Illustrations. 5s.

**The Electro-Platers' Handbook.** A Practical Manual for Amateurs and Students in Electro Metallurgy. By G. E. BONNEY. With 61 Illustrations. 3s.

**Electric Light Cables, and the Distribution of Electricity.** By STUART A. RUSSELL, Assoc.M.Inst.C.E., M.I.E.E. With 110 Illustrations. 10s. 6d.

**Electric Traction.** A practical Handbook on the Application of Electricity as a Locomotive Power. By J. H. RIDER, M.I.E.E., M.I.C.E., Chief Electrical Engineer to the Tramways. With numerous Illustrations. 10s. 6d. net.

**Central Station Electricity Supply.** By A. GAY, M.Inst.E.E., and C. H. YEAMEN, A.Inst.E.E. With 300 Illustrations. 10s. 6d. net.

**Electric Motors**—Induction Motors and Continuous Current Motors, Their Theory and Construction. By H. M. HOBART, B.Sc., M.I.E.E., Mem. A.I.E.E. With 480 Illustrations. 12s. 6d. net.

**The Alternating-Current Circuit and Motor.** An Introductory and Non-Mathematical Book for Engineers and Students. By W. PERREN MAYCOCK, M.I.E.E. With 140 Illustrations. 4s. 6d. net.

**The Practical Telephone Handbook and Guide to Telephone Exchanges.** By JOSEPH POOLE, A.I.E.E. (Wh. Sc.). With 480 Illustrations. 6s. net.

**Alternate Currents in Practice.** A Practical Treatise upon their Application to Industries. Translated from the French of LOPPÉ & BOUQUET by F. J. MOFFETT, A.Inst.E.E. With 288 Illustrations. 6s.

**Whittaker's Electrical Engineers' Pocket-Book.** Edited by KENELM EDGECUMBE, A.M.I.E.E. With 143 Illustrations. Leather, gilt edges, 3s. 6d. net.

---

*Catalogue of Books on Electricity, Engineering, &c., post free.*

WHITTAKER & CO., 2 WHITE HART STREET, PATERNOSTER SQUARE,  
LONDON, E.C.



- Kapp's Electric Transmission of Energy, 10s. 6d.  
 — Transformers, 6s.  
 Lamps, Electric, Maycock, 6s.  
 Land Measuring Tables, Cullyer, 2s. 6d.  
 — Surveying, Middleton, 5s.  
 — Surveying and Levelling, Walmisley, 6s. net.  
 — Field Work and Instruments, Walmisley, 5s.  
 Landolt's Optical Activity and Chemical Composition, 4s. 6d.  
 Lathes, Horner, 6s.  
 Leather Work, Leland, 5s.  
 Leland's Wood-carving, 5s.  
 — Metal Work, 5s.  
 — Leather Work, 5s.  
 — Drawing and Designing, 2s.  
 — Practical Education, 6s.  
 Lens Work, Orford, 3s.  
 Lenses, Photographic, Taylor, 3s. 6d. net.  
 Lightning Conductors, Lodge, 15s.  
 Locomotive Engineer, McDonnell, 1s.  
 Locomotives, Cooke, 7s. 6d.  
 — Development, Cooke, 2s. 6d.  
 Lodge's Lightning Conductors, 15s.  
 Logarithms for Beginners, Pickworth, 1s.  
 Loppé and Bouquet's Alternate Currents, 6s.  
 Lubrication, Wheeler, 3s. net.  
 Lunge and Hurter's Alkali Makers' Handbook, 10s. 6d.  
 McDonnell, How to become a Loco. Engineer, 1s.  
 Maginnis' Atlantic Ferry, 2s. 6d.  
 Magnetism and Electricity, Ashworth, 2s. 6d.  
 — — Bottone, 2s. 6d. net.  
 — — Houston, 2s. 6d. net.  
 — — Maycock, 2s. 6d. net.  
 Manual Instruction, Woodwork, Barter, 6s.  
 — — Drawing, Barter, 3s. 6d.  
 — — Metal Work, Miller, 3s. 6d.  
 Manures, Griffiths, 7s. 6d.  
 Marine Engineers, advice to, Roberts, 2s. 6d.  
 — Drawing and Designing, Roberts, 6s.  
 — Drawing Cards, Sothern, 3s. 6d. net.  
 — Electric Lighting, Walker, 5s.  
 — Questions and Answers, Wanan and Sothern, 3s. 6d. net.  
 Marine Verbal Notes and Sketches, Sothern, 5s. 6d. net.  
 Marshall's Cakes, 1s.  
 — Cookery, 1s.  
 Masee's The Plant World, 2s. 6d.  
 Mathematical Tables, Hutton, 12s.  
 Mathematics, Elementary, Hatton, 2s. 6d.  
 May's Ballooning, 2s. 6d.  
 Maycock's Electricity and Magnetism, 2s. 6d.  
 — Electric Lighting and Power Distribution, vol. i. 6s.; vol. ii. 7s. 6d.  
 — Alternating Current Circuit and Motor.  
 — Electric Wiring, Fittings, Switches, and Lamps, 6s.  
 — — Details Forms, 2s. 6d. net.  
 — Electric Wiring Tables, 3s. 6d.  
 Mazzotto's Wireless Telegraphy and Telephony.  
 Measurements, Electrical, Crapper, 2s. 6d.  
 — — Hobbs, 1s. net.  
 — — Houston, 4s. 6d. net.  
 Mechanical Tables, Foden, 1s. 6d.  
 — Refrigeration, Williams, 10s. 6d.  
 Mechanical Engineer's Pocket-Book, Björling, 3s. 6d. net.  
 Medical Terms, Hoblyn, 10s. 6d.  
 Metal Turning, Horner, 3s. 6d.  
 — Work, Leland, 5s.  
 — — Miller, 3s. 6d.  
 Metric System, Wagstaff, 1s. 6d.  
 Middleton's Surveying and Surveying Instruments, 5s.  
 Mill Work, Sutcliffe, 10s. 6d.  
 Miller's Metal Work, 3s. 6d.  
 Millinery, Ortner, 2s. 6d.  
 Mine, Coal, Boyd, 3s. 6d.  
 Mineralogy, Hatch, 2s. 6d.  
 Model Engines, Alexander, 6s. net.  
 Modern Safety Bicycle, Garratt, 3s.  
 Motor Cars, Farman, 5s.  
 Motors, Electric, Bottone, 3s.  
 — — Hobart, 12s. 6d. net.  
 — Hydraulic, Bodmer, 15s.  
 Municipal Electricity Supply, Gibbings, 6s.  
 Nadiéine, Drainage, 1s.  
 Neuman and Baretto's Spanish Dictionary, 2 vols. 21s.  
 Neumann's Electrolytic Analysis, 6s.  
 Nicolson's Telegraphic Vocabulary, 3/ 10s. net.

- Optical Activity and Chemical Composition, Landolt, 4s. 6d.  
 Optical Instruments, Orford, 2s. 6d.  
 Optics, Geometrical, Blakesley, 2s. 6d. net.  
 — of Photography, Taylor, 3s. 6d. net.  
 Orford's Lens Work, 3s.  
 — Optical Instruments, 2s. 6d.  
 Organic Chemical Manipulation, Hewitt, 4s. 6d.  
 Ortner's Millinery, 2s. 6d.  
 Owen's Telephone Lines, 5s.  
 Parliamentary Companion, Dod, 4s. 6d.  
 Pattern Making, Horner, 3s. 6d.  
 Peamage, Dod, 10s. 6d.  
 Percentage Tables for Analysis, Guttman, 3s. net.  
 Periodic Classification and Chemical Evolution, Rudorf, 4s. 6d.  
 Petroleum, Boyd, 2s.  
 Pharmacy, Thompson.  
 Photographic Lenses, Taylor, 3s. 6d. net.  
 Physical Chemistry, Reychler, 4s. 6d.  
 Pickworth's Indicator Handbook, 2 vols. 3s. each, net.  
 — Logarithms for Beginners, 1s.  
 — Slide Rule, 2s.  
 Pipes and Tubes, Björling, 3s. 6d. net.  
 Plant World, Massee, 2s. 6d.  
 Planté's Electric Storage, 12s.  
 Plumbing and Sanitary Fittings, Sutcliffe, 5s. net.  
 Poole's Telephone Handbook, 5s.  
 Practical Education, Leland, 6s.  
 Preece's Telephony, 15s.  
 Price's Hoblyn's Dictionary of Medical Terms, 10s. 6d.  
 Quantities and Quantity Taking, Davis, 3s. 6d. net.  
 Radiography and X Rays, Bottone.  
 Radium, Bottone, 1s. net.  
 Railway, Electric, Hering, 4s. 6d. net.  
 — Management, Findlay, 7s. 6d.  
 — Material Inspection, Bodmer, 5s.  
 — Vocabulary, French - English, Serrailier, 7s. 6d. net.  
 Refrigeration, Williams, 10s. 6d.  
 Repoussé, Leland, 5s.  
 Reychler's Physical Chemistry, 4s. 6d.  
 Rider's Electric Traction, 10s. 6d. net.  
 Road Construction, Greenwell and Elsdon, 5s. net.  
 Roberts' Drawing for Marine Engineers, 6s.  
 — Advice to Marine Engineers, 2s. 6d.  
 Röntgen's X Rays, Bottone, 3s.  
 Rudorf's Periodic Classification and Chemical Evolution, 4s. 6d.  
 Russell's Electric Cables, 10s. 6d.  
 Safety Bicycle, Garratt, 3s.  
 Saints and their Symbols, Greene, 3s. 6d.  
 Salomons' Electric Light Installations. Vol. II., Apparatus, 7s. 6d.  
 — Management of Accumulators.  
 — Vacuum Tubes, 2s.  
 Sanitary Drainage, Nadiéine, 1s.  
 — Fittings and Plumbing, Sutcliffe, 5s. net.  
 Sennett's Carriages without Horses, 2s.  
 — Fragments from Continental Journeys, 4s. 6d. net.  
 Serrailier's Railway Vocab., French-English, 7s. 6d. net.  
 Slide Rule, Pickworth, 2s. net.  
 Sloyd, English, Barter, 6s.  
 Sothorn's Verbal Notes and Sketches for Marine Engineers, 5s. 6d. net.  
 — Questions and Answers for Marine Engineers, 3s. 6d. net.  
 — Drawing Cards for Marine Engineers, 3s. 6d. net.  
 Spanish Dictionary, Neuman and Baretti, 21s.  
 Specialists' Series.  
 Specifications for Building Work, Farrow, 3s. 6d. net.  
 Steam Jacket, Fletcher, 1s. 6d.  
 — Locomotives, Cooke, 7s. 6d.  
 — Model Engines, Alexander, 6s. net.  
 — Power and Mill Work, Sutcliffe, 10s. 6d.  
 Steamships, Atlantic, Maginnis, 3s. 6d.  
 Steel Works Analysis, Arnold, 10s. 6d.  
 — and Iron Structures, Twelv-trees, 6s. net.  
 — Concrete, Twelv-trees, 6s. net.  
 Still's Alternating Currents, 5s.  
 Storage Battery, Treadwell, 7s. 6d. net.  
 Stresses and Strains, Farrow, 5s. net.  
 Structural Iron and Steel, Twelv-trees, 6s. net.  
 Stubbs' Telephony, 15s.  
 Surveying and Surveying Instruments, Middleton, 5s.  
 — and Levelling, Walmisley, 6s. net.

- Surveying Field Work and Instruments, Walmisley, 5s. net.  
 Sutcliffe's Steam Power and Mill Work, 10s. 6d.  
 — Sanitary Fittings and Plumbing, 5s. net.  
 Switches, Electric, Maycock, 6s.  
 Tables, Electric Wiring, Maycock, 3s. 6d.  
 — Mathematical, Hutton, 12s.  
 — Mechanical, Foden, 1s. 6d.  
 — Percentage, for Analysis, Guttman, 3s. net.  
 Taylor's Optics of Photography, 3s. 6d. net.  
 Teacher's Handbook of Metal Work, Miller, 3s. 6d.  
 Technological Dictionaries, Webber.  
 Telegraphic Vocabulary, Nicolson, 3/ 10s. net.  
 Telegraphy, Herbert.  
 — Wireless, Bottone, 3s.  
 — Wireless, Mazzotto.  
 Telephone System of the British Post Office, Herbert, 3s. 6d.  
 — Handbook, Poole, 5s.  
 — Lines, Owen, 5s.  
 — Service, Webb, 1s. net.  
 Telephony, Preece, 15s.  
 Thompson's Chemist's Compendium, 2s. net.  
 Thomson's Apothecaries Hall Manual, 2s. net.  
 Thwaite's Gaseous Fuel, 1s. 6d.  
 Traction, Electric, Rider, 10s. 6d. net.  
 Transformers, Kapp, 6s.  
 — Still, 5s.  
 Treadwell's Storage Battery, 7s. 6d. net.  
 Trigonometry, Adams, 2s. 6d. net.  
 Tubes and Pipes, Björling, 3s. 6d. net.  
 — Vacuum, Salomons, 2s.  
 Turbines and Hydraulic Motors, Bodmer, 15s.  
 Turner and Hobart's Insulation of Electric Machines, 10s. 6d. net.  
 Turning Metal, Horner, 3s. 6d.  
 Twelvrees' Structural Iron and Steel, 6s. net.  
 Twelvrees' Concrete-Steel, 6s. net.  
 Vacuum Tubes, Experiments, Salomons, 2s.  
 Verbal Notes and Sketches for Marine Engineers, Sothorn, 5s. 6d. net.  
 Volumetric Analysis, Coppock, 2s.  
 Wagstaff's Metric System, 1s. 6d.  
 Walker's Electricity in Homes, 6s.  
 — Electric Lighting for Marine Engineers, 5s.  
 Wallis and Hawkins' Dynamo, 15s.  
 Walmisley's Field Work and Instruments, 5s. net.  
 — Land Surveying and Levelling, 6s. net.  
 Wannan and Sothorn's Questions and Answers for Marine Engineers, 3s. 6d. net.  
 Webb's The Telephone Service, 1s. net.  
 Webber's Technical Dictionary, 4 vols., English, German, French, Italian.  
 Wheeler's Friction, its Reduction, 3s. net.  
 Whittaker's Mechanical Engineer's Pocket-Book, 3s. 6d. net.  
 — Electrical Engineer's Pocket-Book.  
 Williams' Mechanical Refrigeration, 10s. 6d.  
 Wireless Telegraphy, Bottone, 3s.  
 — Telegraphy, Mazotto.  
 Wiring, Electric, Maycock, 6s.  
 — — Details Forms, 2s. 6d. net.  
 — — Tables, Maycock, 3s. 6d.  
 Wood Carving, Leland, 5s.  
 — — Patterns, Andreen, 7s. 6d. net.  
 Wood's Discount Tables, 1s.  
 Woodwork, Barter, 6s.  
 — Drawing, 3s. 6d.  
 — Joints, Adams, 1s.  
 Woven Design, Colour in, Beaumont, 21s.  
 Wyatt's Differential and Integral Calculus, 3s. 6d.  
 X Rays, Bottone.  
 Yeaman and Gay's C. S. Electricity Supply.

Complete Catalogue of Technical and Scientific Books, Post Free,

WHITTAKER & CO.

2 WHITE HART STREET, PATERNOSTER SQUARE, LONDON, E.C.

